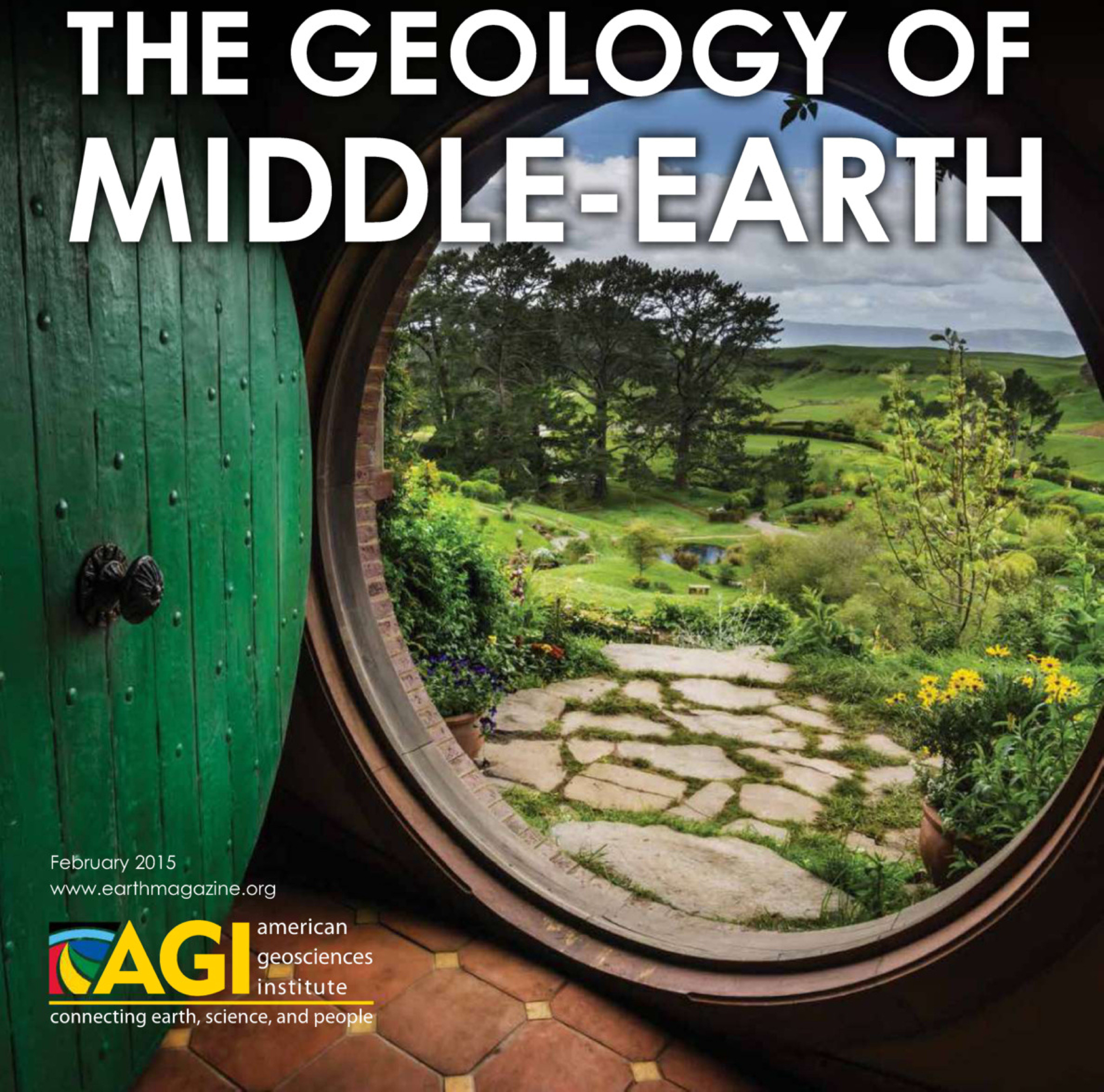
U.S. MILITARY PREPARING FOR CLIMATE CHANGE

PROTECTING MINERAL TREASURES IN ANTARCTICA

NEW TRACERS IDENTIFY FRACKING FLUIDS

EARTH

THE GEOLOGY OF MIDDLE-EARTH



February 2015
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EARTH

FEATURES

VOICES

ON THE COVER: Looking out on the "shire" from Bilbo Baggins' hobbit hole in "Hobbiton" — near real-life Matamata, New Zealand.

NEWS

DEPARTMENTS

From the Editor

Upon hearing that their favorite book is being made into a movie, readers are often filled with both joy at the prospect of seeing beloved characters brought to life on the big screen, and trepidation about whether the film will do justice to the book. Whether it does often largely depends upon casting.

When producer and director Peter Jackson set out to make two film trilogies of J.R.R. Tolkien's classic fantasy epics, "The Lord of the Rings" and "The Hobbit," he cast some notable stars of stage and screen. However, in all six of the films, there was an additional, uncredited character that appeared in almost every scene and arguably played the largest role of all: the geology of Middle-earth.

Readers of Tolkien's works, in which Middle-earth's extensive and varied landscape is described in meticulous detail, are as familiar with Tolkien's maps as they are with his epic storylines, his vast cast of characters and his wholly invented languages. To portray this landscape, Jackson cast his home country of New Zealand, a rugged and beautiful terrain with a geologic history more epic than anything Tolkien himself could have imagined. On film, the Southern Alps stood in for the Misty Mountains, Mount Doom was portrayed by Mount Ngauruhoe, and Mordor was played by the volcanics of Tongariro National Park, including Taupo supervolcano.

Filmgoers, and readers of Tolkien's books, were so pleased with the portrayal of Middle-earth on film that a new industry has now been spawned in New Zealand: "The Lord of the Rings" tourism, in which sightseers make pilgrimages to the country's more than 100 film locations. For the geologically oriented fan, there is even a "Lord of the Rings" geology field camp. This month, EARTH roving correspondent and Tolkien fan Terri Cook takes us along on just such a quest in her feature "The Geology of Middle-earth."

We also travel this month to the real-world destinations of Bermuda, where contributor Sam Lemonick leads us on a historical and geological tour of the island nation's pink sand beaches, shipwrecks and forts. Then we travel with mineralogists Edward S. Grew and Christopher J. Carson to the Larsemann Hills of Antarctica, now designated as an Antarctic Specially Protected Area — largely because of the authors' efforts — for its significant mineral diversity.

So join us! Step out your door and into the pages of EARTH. There's no knowing where you might be swept off to.

Sara E Pratt

Sara E. Pratt
EARTH Associate Editor

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MISSED IN SCOTLAND

In your December 2014 cover story on Scotland, I was somewhat disappointed to see no mention of the spectacular exposures at Siccar Point along the Scottish coast east of Edinburgh. The angular unconformity there was discovered by James Hutton and proved that Earth had a history with "no vestige of a beginning and no prospect of an end" (Hutton's words). Geology as a science began with that discovery. Also, no mention was made that the rocks of northwestern Scotland began life as a part of Laurentia and only became attached to what is now Scotland in post-Cambrian time.

A.R. (Pete) Palmer
Boulder, Colo.

AGE OF THE UNIVERSE

I just finished reading the November/December 2014 issue. Wonderful, as always. I have one question. In the story, "High-powered simulation tracks evolution of the universe in detail," Lizzie Reinthal states that the universe burst into existence 14.6 billion years ago. The number I have always seen in astronomy articles is 13.8 billion. Have I missed some major new discovery about the age of the universe?

Thanks for listening. Your magazine is the first thing I read as soon as I get it. Great job.

Nel Graham
Pasadena, Calif.

EDITOR'S NOTE:

Thank you for your message. Our understanding is that the accepted 13.8-billion-year-old age is the average of all of the proposed methodologies for measuring the age of the universe — which vary from about 12 billion to 15 billion years old. The accepted average is the 13.8-billion-year-old age for the lack of anything more definitive. An astrophysicist colleague tells us that the 14.6-billion-year-old age Reinthal mentions comes from estimates of examining luminosity in globular clusters and is one of the methodologies with an older proposed age. Hope that helps!

POLL: REMOTELY TRIGGERING QUAKES

In November, we asked our readers: When you hear about a major earthquake halfway around the world, are you concerned about your own seismic risk? Here are the results:*

No, I don't live in a seismically active area	38%
Yes, because large quakes can trigger distant aftershocks elsewhere	17%
No, I don't worry about earthquakes in general	17%
Yes, because it reminds me of my everyday seismic risk locally	17%
No, I'm not convinced earthquakes can trigger distant aftershocks	9%
Don't know	2%

*This poll is not scientific and reflects the opinions only of those Internet users who have chosen to participate.

CORRECTION

Angkor Wat, a location mentioned in Terri Cook's commentary "What a wonderful world to explore" in the December 2014 issue, is in Cambodia, not Thailand as originally stated.

EARTH welcomes letters to the editor. All letters are subject to editing for length and clarity. Send letters to: earth@earthmagazine.org.

Visit our polls online at www.earthmagazine.org

Earth Exposures

Flint Hills, Kansas

Michael Collier

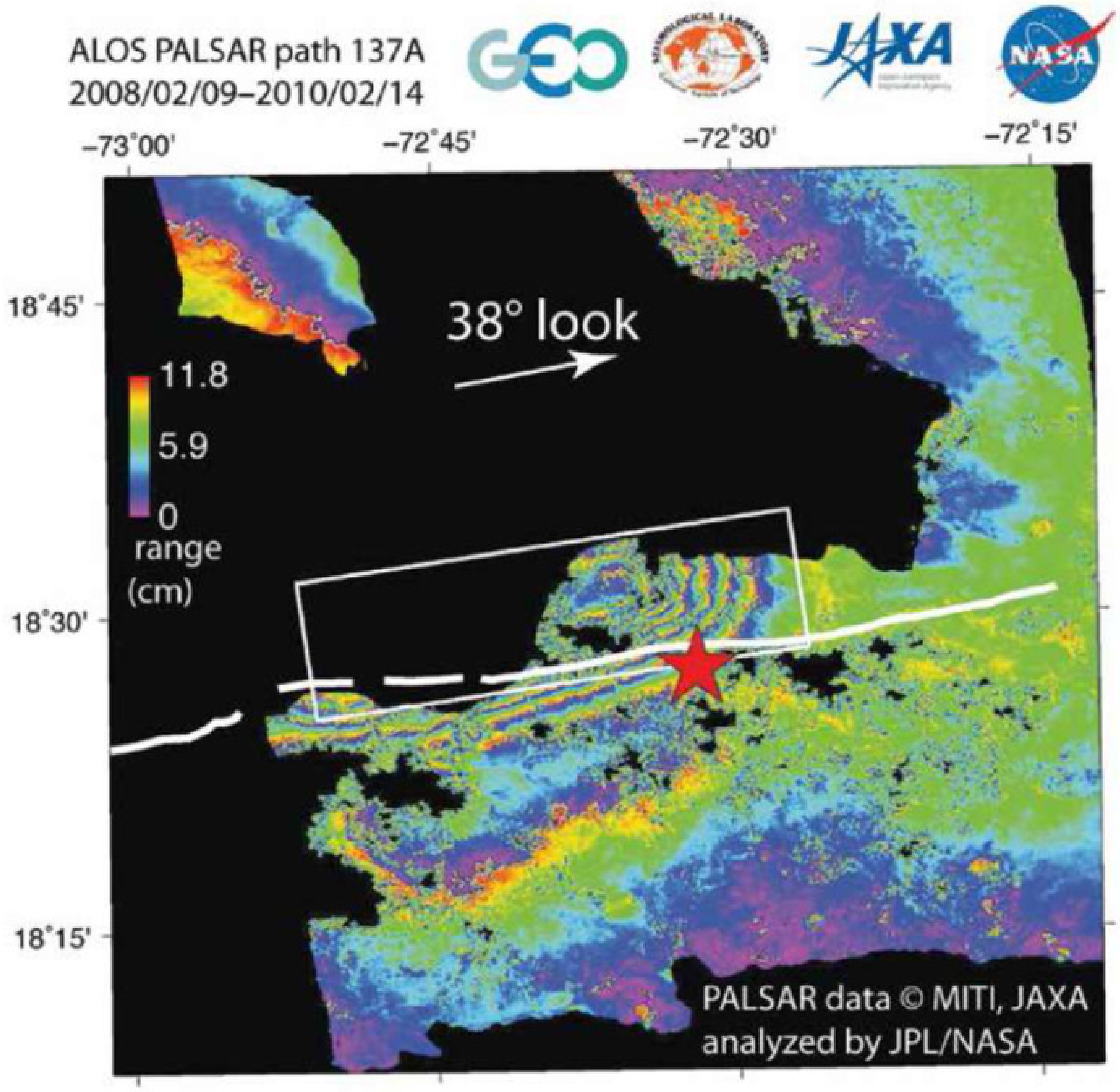
Permian-aged limestone and shale are exposed in the Flint Hills of eastern Kansas. Flint Hills draws its name from prominent bands of chert — mineralogically, flint is black chert — that weather out to form resistant gravel lenses. Today, the hills are a refuge for the largest preserved stand of tallgrass prairie in the country.

Collier, a geologist, photographer, pilot and author, took this photo in 2011.

Supersites:
Sharing Geoscience Data for Science and Society

Linda R. Rowan

When major geologic hazards strike, they gain global attention. Disaster responders and scientists want remote sensing and in-situ observations of the site in order to respond faster and learn more about the event. Satellites operated by many countries as well as commercial entities provide eyes in the sky, while ground-based networks of seismic, geodetic, geochemical and other instrumentation keep ears to the ground. In the past decade, the United Nations has organized the Group on Earth Observations (GEO), a collaboration of 89 institutions and organizations that sustain comprehensive Earth-observing capabilities for the benefit of humankind. GEO has six global objectives, including the Geohazard Supersites and Natural Laboratories (GSNL) initiative. GSNL is a unique international collaboration focused on sharing spaceborne and other geophysical data to understand geohazards and to promote preparedness and hazard mitigation. GSNL has had several successes already and is poised for many more.



The Geohazard Supersites and Natural Laboratories initiative, a network of Earth-observing institutions, can designate certain natural disasters "event supersites" to help coordinate the collection and distribution of crucial data needed by first responders and scientists. Such data helped produce this map of surface deformation caused by the magnitude-7 earthquake in Haiti in January 2010.
Credit: Eric Fielding/JPL/NASA/JAXA

The two primary goals of GSNL are to acquire data for specific supersites and to build a cyber-infrastructure to integrate, archive and provide open access to data and data products. The European Space Agency provides a cloud-based archive of European satellite synthetic aperture radar (SAR) data, and UNAVCO maintains the GSNL data site and coordinates the Western North America InSAR Consortium. Supersites are single hazardous sites (such as one volcano) with ground-based observational infrastructure where shared spaceborne and other geophysical data would benefit research and hazards mitigation. Some of the most coordinated supersites include volcanoes and faults in Ecuador, Iceland, Italy, New Zealand and Turkey. In the future, some supersites or other regions will hopefully become natural laboratories, which are larger regions that encompass a coherent tectonic setting.

Hawaii was the first supersite and is an excellent example of the potential of GSNL. The island of Hawaii, where Kilauea Volcano has been erupting continuously from the East Rift Zone since 1983 and from the summit since 2008, is well instrumented on the ground, but researchers depend on the sharing of satellite data for remote sensing. Over the past decade, SAR data from multiple satellites have revealed insights into volcanic and seismic activity at Kilauea by tracking ground deformation and subsurface change related to magma dynamics, eruptions and earthquakes.

SAR images taken on different days are processed together to create

interferometric images (InSAR), which show one-dimensional changes of Earth's surface along the radar line of sight; this technique has been used extensively for geohazards monitoring. In June 2007, SAR captured a magmatic intrusion and eruption at Kilauea. Access to this data, facilitated by GSNL, helped researchers develop a technique that combines multiple aperture interferometry with InSAR to yield a 3-D image of surface deformation. Such data provided a fuller view of the ground motion associated with emplacement of a dike than was available from standard InSAR or ground-based data like GPS alone.

This global initiative represents an organized approach to hazards mitigation and preparedness that efficiently leverages a multitude of remote sensing and ground-based monitoring resources for science and society.

Another innovation, called SAR coherence mapping, can delineate a fresh lava flow based on the scattering properties of the surface. Fresh lava causes a radar signal to decorrelate in interferograms, allowing new flows to be distinguished from older lava flows.

SAR data from Kilauea acquired through the supersite have been used to identify instabilities along the rim of the eruptive vent at the volcano's summit. Such instabilities may be indicators of the potential for hazardous rim collapses, which may endanger scientists or tourists near the crater. Because ground-based instrumentation cannot be installed near the vent rim due to ground instability there, SAR represents the primary tool available to measure ground deformation in the area.

GSNL has the ability to create "event supersites" when a geohazard strikes. The large and destructive earthquakes in Haiti (magnitude 7 in 2010) and in Tohoku (magnitude 9 in 2011) were rapidly approved as event supersites, in which space agencies, ground-based network operators and the scientific community were mobilized under very different scenarios.

Haiti had a very limited earthquake-monitoring network, and although instruments were rapidly deployed after the mainshock, satellite data provided critical information. These data are widely used. For example, within two months of the Haiti earthquake, 212 visitors (114 universities, 85 research institutions and 13 private-sector organizations) downloaded SAR data from a satellite operated by the Japan Aerospace Exploration Agency from the GSNL website. Remote sensing and ground-based data from multiple agencies provided information about the fault that ruptured, the amount and direction of surface deformation, the locations of landslides and liquefaction, and the continuing effects of the mainshock and thousands of aftershocks.

Most compellingly for society, the research showed that the earthquake occurred on a previously unmapped fault. The Enriquillo Fault — thought to be the main seismic hazard in the region — did not show much slip, meaning the potential for a large event on the island of Hispaniola, shared by Haiti and the Dominican Republic, remains high.

Japan already had a significant and sophisticated earthquake monitoring network, in addition to its own Earth-observing satellites. The Tohoku earthquake was a massive event that partially crippled some of the seismic network. The subsequent tsunami wreaked havoc on Japan's complex infrastructure.

The International Charter on Space and Major Disasters initiated sharing of remote sensing data for response and rescue, while the GSNL members and many others worked with the shared data to understand the tectonic processes associated with the earthquake. During the first two weeks after the earthquake, about 4,500 visitors accessed the Tohoku event supersite and about 20,000 downloads of SAR images were recorded in the first month.

Even though the earthquake occurred offshore, where there is little in-situ monitoring, the combination of GPS and InSAR data allowed researchers to determine that the earthquake displaced some parts of the island of Honshu downward about 1.5 meters, eastward about 5 meters and southward about 2 meters. The direction and amount of deformation observed on the surface helped elucidate fault dynamics and provided insight into the likelihood of future earthquakes throughout Japan. Much was learned about the earthquake and tsunami, including lessons that can be applied to other major subduction zones, such as those in western North America, South America and Southeast Asia.

This global initiative represents an organized approach to hazards mitigation and preparedness that efficiently leverages a multitude of remote sensing and ground-based monitoring resources for science and society. GSNL is well on its way to fulfilling GEO's mission "to realize a future wherein decisions and actions, for the benefit of humankind, are informed by coordinated, comprehensive and sustained Earth observations and information."

Credit: Abigail Seadler

Rowan is director of external affairs at UNAVCO, Inc., where she helps to advance geodetic-based research and geodetic data sharing for societal benefit in the U.S. and throughout the world. The views expressed are her own.

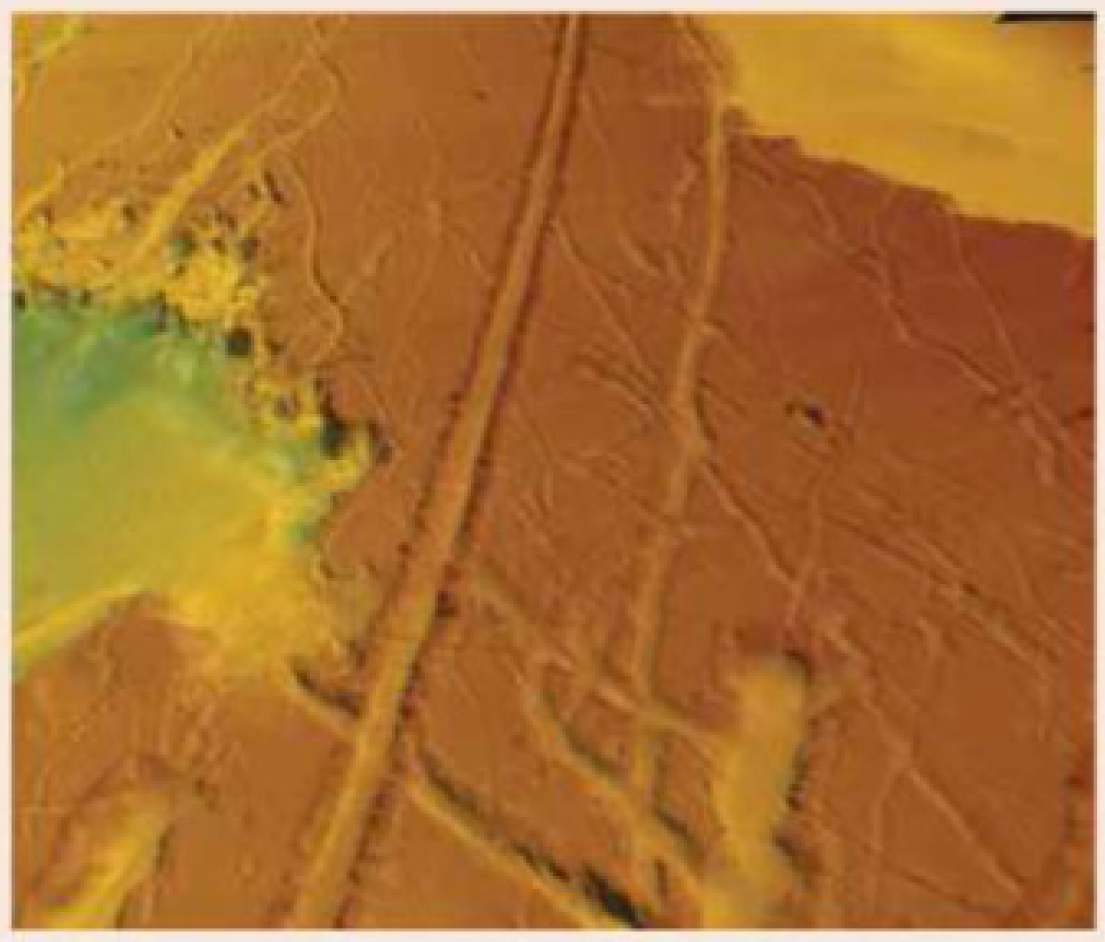
Icebergs were the original Florida snowbirds

A new study shows that between 20,000 and 10,000 years ago, icebergs drifted southward off the coasts of South Carolina and Florida.

Using multibeam bathymetry data, Jenna Hill at Coastal Carolina University in Conway, S.C., and Alan Condron of the University of Massachusetts mapped a number of long scars on the seafloor that they attribute to scour marks left by icebergs journeying south. The scars — up to 30 kilometers long, 100 meters wide and 20 meters deep — were detected between Cape Hatteras and the Florida Keys. Their shapes and distribution suggest the scars were left by massive south-going icebergs up to 300 meters thick.

In the study, published in Nature Geoscience, oceanic circulation models suggest that the icebergs were riding south on cold coastal currents generated during periods of intense melting from the Laurentide ice sheet that once covered eastern North America. Hill and Condron proposed that glacial floodwaters formed a narrow current about 100 kilometers wide that ran from the tip of Newfoundland south along the continental shelf. Icebergs carried by the cold conveyor could have reached South Carolina within a few months, and periods of high ice-sheet melting could have carried the bergs all the way to Florida.

Mary Caperton Morton



As icebergs drifted south along the coast, their keels plowed across the seafloor, creating the characteristic grooves shown here in a seafloor bathymetry image from offshore of South Carolina.

Credit: Jenna C. Hill

Secondary aerosols a primary cause of Chinese smog

Images of Chinese skylines and streetscapes blurred by pollution-fueled hazes have become increasingly common in recent years amid ongoing urbanization and industrialization. According to a new study published in Nature, much of the pollution fogging the country's major cities is arising not from fine particles emitted directly into the sky, but by gases that react and condense in the atmosphere to form secondary aerosols.

January 2013 was particularly bad for pollution, with air-quality measurements across dozens of Chinese cities revealing levels of fine particulates — that is, particles less than 2.5 micrometers in diameter, collectively known as PM2.5 — that exceeded national standards on 69 percent of days that month.

To better understand the makeup and sources of the haze, scientists collected daily air samples through January in four geographically distant cities: Beijing, Guangzhou, Shanghai and Xi'an. In the first three cities, secondary aerosols accounted for more than half — between 51 and 77 percent on average — of fine particulate pollutants. In Xi'an, the contribution of secondary aerosols was about 30 percent, although the city had far higher levels of particulate pollution overall due to high levels of airborne dust. The leading sources of the secondary aerosols — which form largely from precursor volatile organic compounds and inorganic sulfur and nitrogen gases — were traffic, coal and biomass burning, and cooking, all of which also directly emit large amounts of primary aerosols.

The study "suggests that emission control strategies to mitigate PM2.5 pollution in China should, in addition to primary particulate emissions, also address the emission reduction of secondary aerosol precursors," Ru-Jin Huang of Switzerland's Paul Scherrer Institute and colleagues wrote.

Timothy Oleson

Taken one day apart — on Jan. 31 (left) and Feb. 1, 2013 (right) — these photos of Beijing's National Stadium hint at the scale of China's pollution problem.

Credit: both: Ru-Jin Huang and Jun-Ji Cao

Pentagon report calls for military to prepare for climate change

The U.S. Department of Defense (DOD) is charged with ensuring national security against threats, both domestic and foreign. Now the Pentagon has released a report detailing its strategy against a developing foe: climate change. The 20-page "Climate Change Adaptation Roadmap" outlines actions the military can take to adapt to and mitigate the effects of climate change, both at home and internationally.

"Climate change does not directly cause conflict, but it can significantly add to the challenges of global instability, hunger, poverty and conflict. Food and water shortages, pandemic disease, disputes over refugees and resources, more severe natural disasters — all place additional burdens on economies, societies and institutions around the world," wrote then-Secretary of Defense Chuck Hagel in a foreword to the report.

"Weather has always affected military operations, and as the climate changes, the way we execute operations may be altered or constrained," he wrote. "While scientists are converging toward consensus on future climate projections, uncertainty remains. But this cannot be an excuse for delaying action."

The report details how the DOD can begin adapting its plans and operations in the face of climate change, broadly calling for increased training of forces and equipment testing, improvements to infrastructure and stabilization of supply chains for emergency provisions.

More specifically, the report breaks down a few of the potential threats from climate change, which the report called a "threat multiplier" and an "immediate risk to national security." For example:

- Rising sea levels may lead to increased storm surges and flooding of coastal defense structures and military bases, as well as impact the execution of amphibious landings in combat situations.
- The opening of formerly frozen Arctic sea lanes will increase the need for air, sea and land capabilities and capacity in the Arctic region in order for the DOD to monitor events, safeguard freedom of navigation, and ensure stability in this resource-rich area.
- Increased frequency of extreme weather could impact aviation as well as intelligence, surveillance and reconnaissance capability. Recovery from extreme weather events could require increased intervention from the National Guard.
- Drought may impact operations, creating water shortages and fire hazards. Dust may become more of a factor during training activities, which may interfere with sensitive equipment, or may require more extensive dust control measures to meet environmental compliance requirements.
- Stressed, threatened and endangered species and related ecosystems, on and adjacent to DOD installations, may result in changing land management requirements that could affect training and operations protocols.

Climate change is a global phenomenon and accordingly, the scope of the report is international: "The impacts of climate change may cause instability in other countries by impairing access to food and water, damaging infrastructure, spreading disease, uprooting and displacing large numbers of people, compelling mass migration, interrupting commercial activity, or restricting electricity availability," the report states.

In addition, the report states, "these developments could undermine already fragile governments that are unable to respond effectively or challenge currently stable governments, as well as increasing competition and tension between countries vying for limited resources. These gaps in governance can create an avenue for extremist ideologies and conditions that foster terrorism."

The report was presented during Hagel's speech at the 11th Conference of Defense Ministers of the Americas, held in Peru in October.

Mary Caperton Morton

Scientists complete a global inventory of lakes

How many lakes are there in the world? Until recently, the exact number was anybody's guess. Now, a new global inventory conducted using satellite imagery has placed the count at 117 million. The GLObal WAter BOdies database (GLOWABO) includes all lakes greater than 0.002 square kilometers, which combined, cover a surface area of 5 million square kilometers, or 3.7 percent of the Earth's nonglaciated land area.

Previously, global lake counts relied on map compilations and statistical extrapolations. The new study, led by Charles Verpoorter of Uppsala University in Sweden and published in Geophysical Research Letters, is the first to take a count using satellite imagery. The new study revealed the actual number of lakes is much lower than previous estimates, which placed the number of lakes at about 304 million, but the total surface area covered is greater than indicated by past estimates.

Mary Caperton Morton

Oregon's Crater Lake is one of more than 117 million newly inventoried lakes around the world.
Credit: Mary Caperton Morton

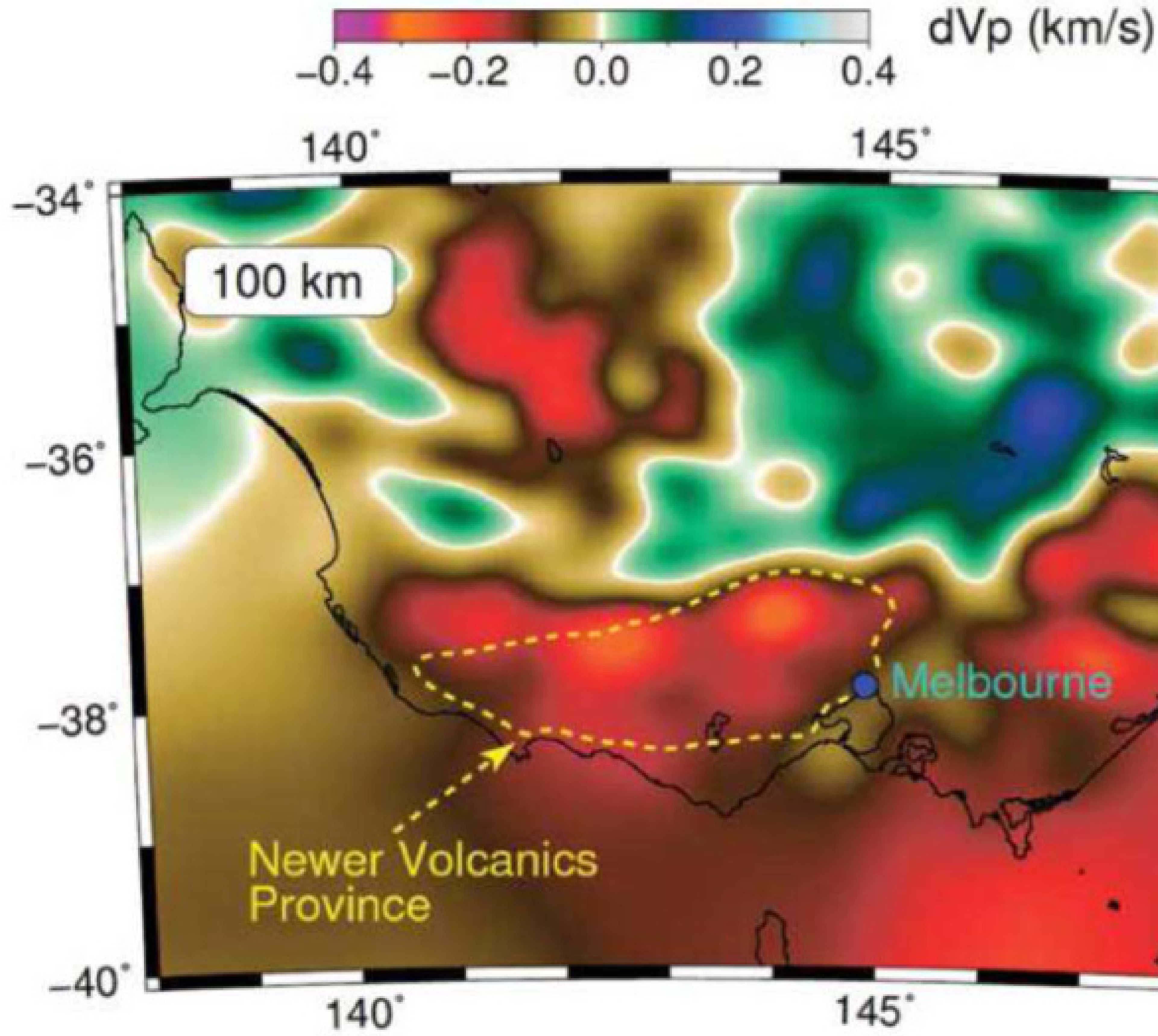
Mantle plume alternative explains Australian volcanism

Magma often finds its way to the surface along Earth's crustal boundaries as tectonic plates crash together, rift apart or grind past each other. Less understood is why volcanoes sometimes emerge far away from plate boundaries. Narrow plumes of buoyant mantle rock rising from hundreds of kilometers deep have long been supposed as the source of intraplate volcanoes, but evidence for plumes is lacking in many areas. Now, in a new study, researchers have reported evidence for an alternative process, known as edge-driven convection, which appears to be driving intraplate volcanism in southeastern Australia.

Immediately west of Melbourne on Australia's southeastern coast sits the roughly 19,000-square-kilometer Newer Volcanics Province (NVP), a region comprising more than 700 volcanoes and eruptive vents ranging in age from 4.5 million to 5,000 years old. Unlike the Hawaiian Islands, which progress from older to younger in a line from northwest to southeast and are the textbook example of mantle-plume-driven volcanism, in the NVP, volcanoes of different ages are jumbled together.

"There is no age progression" in the NVP, explains Rhodri Davies, a geodynamicist at the Australian National University and lead author of the new study, published in Geology. "The volcanism is also aligned perpendicular to the direction of plate motion" rather than parallel as in Hawaii, he says — also inconsistent with the plume hypothesis. These inconsistencies led Davies and his colleague Nicholas Rawlinson of the University of Aberdeen in Scotland to investigate what, if not a plume, might be causing magma to well up from below the plate.

One possible explanation for intraplate volcanism, called edge-driven convection (EDC), was proposed in the mid-1990s. EDC is thought to arise in the mantle where substantial changes in the thickness of the lithosphere — the crust plus the uppermost portion of the mantle — occur. "Australia, being a very old continent, has some very thick cratonic roots," Davies notes, whereas on its eastern edge "it has very thin lithosphere." Temperature gradients at this lithospheric step — from deeper, warmer mantle to shallower, cooler mantle — should induce convection cells that move warm mantle material to shallow depths. If a portion of this warm material melts, it could then rise to the surface and erupt, Davies says.



A map of seismic P-wave velocities at a depth of 100 kilometers beneath southeastern Australia reveals the outline of the Newer Volcanics Province west of Melbourne.

Credit: Rhodri Davies and Nicholas Rawlinson

Using high-resolution seismic data collected in southeastern Australia, Davies and Rawlinson built a detailed 3-D profile of lithospheric depth in the region. Combining this with an understanding of the direction and velocity of the northbound Australian Plate, which moves in the opposite direction of the underlying mantle, they then modeled mantle flow beneath the lithosphere.

The modeling showed evidence for EDC along Australia's southeastern margin. And beyond that, "the highest upwelling velocities were restricted to [an area right below] the NVP," Davies says, suggesting another part of the reason for the volcanism there. From their lithospheric depth profile, the researchers noticed that the NVP is located above a long, narrow notch, or salient, of relatively thin lithosphere that is mostly surrounded by thicker lithosphere. In the model, the salient's orientation with respect to the direction of plate motion appears "to focus [mantle] flow in the region," Davies says, further increasing upwelling velocities and allowing warm mantle rock to reach shallower depths where it can decompress.

"It's a combination of needing thin lithosphere to get the hot material to low enough pressures to melt, and needing high upwelling velocities to essentially refill the melt zone with fresh material,"

Davies says. Just how thin the lithosphere and how high the velocities must be for melting to occur are unclear, he adds, and may depend on factors such as the particular petrology of the local mantle or how much water is present.

The new findings suggest an answer to a longstanding question about EDC, Davies says: Why, if EDC occurs in some places, do we not see surface evidence of it everywhere in the world where substantial changes in lithospheric thickness occur, including all the way around Australia? It may be that EDC does occur in many parts of the mantle, but that the sort of localized, 3-D focusing mechanism seen in the team's modeling is necessary for it to manifest as volcanism at Earth's surface. This "probably explains why you [would] only get it in isolated locations elsewhere," he says, adding that intraplate volcanic regions on Africa's west coast could be other surface expressions of EDC.

"It's a very nice study," bringing the tomography and modeling together, "and then being able to actually test that model," says Scott King, a geophysicist at Virginia Tech University who was part of the team that developed the EDC theory but was not involved in this study. There "appears to be a compelling argument for this type of mechanism to apply in" the NVP, King says. Integrating these results with a more detailed view of the underlying petrology is probably "the next significant step forward."

Timothy Oleson

North American terranes not so exotic after all

The cordillera of western North America is a patchwork of various landmasses, or terranes, that assembled through collision and accretion to the Laurentian Shield, leaving a complicated tectonic history for geologists to unravel.

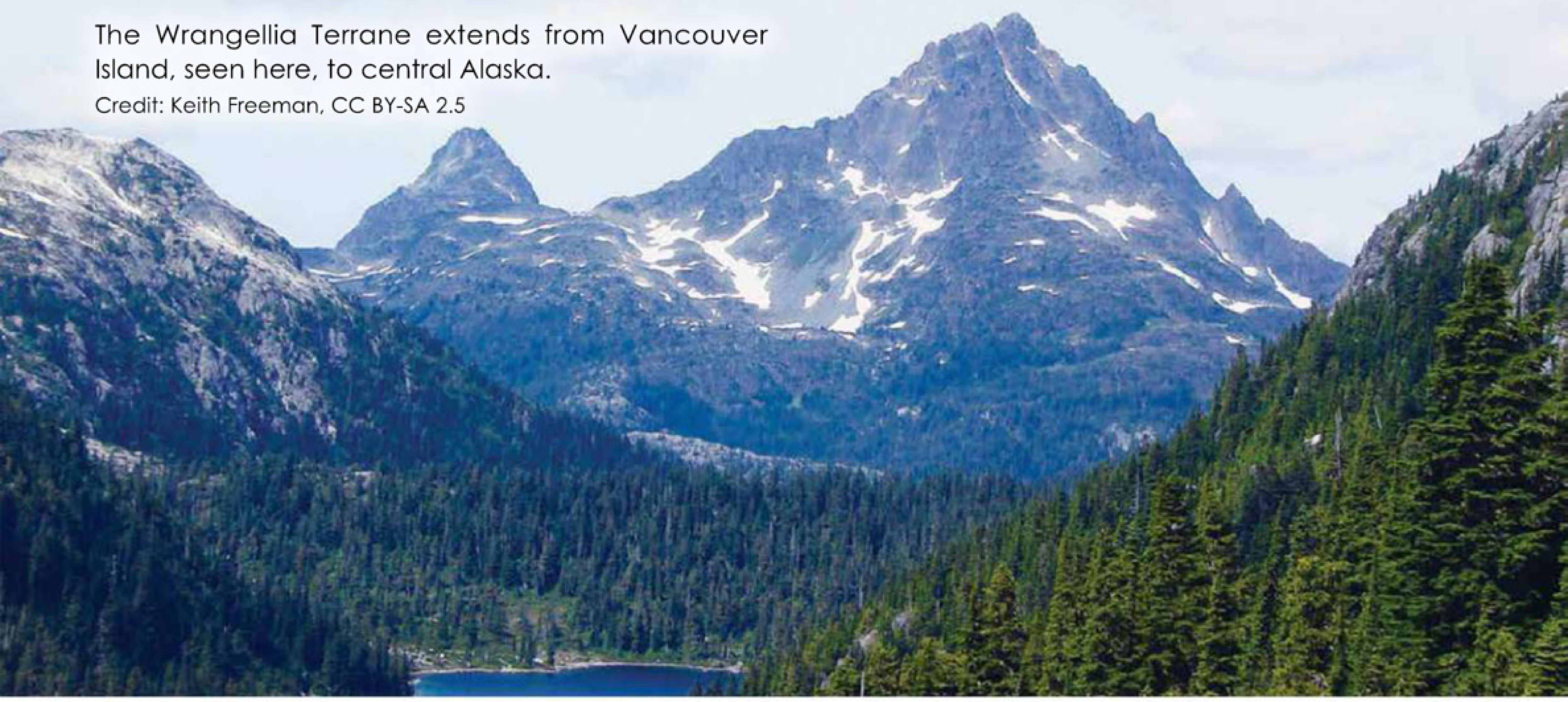
Two of those terranes, the Alexander and Wrangellia, emplaced along western British Columbia, southwest Yukon, and eastern Alaska, have seemingly different geologies and were thought to have evolved separately. Now, a new study in Lithosphere shows that not only do they share a common tectonic history, but that part of the Alexander terrane forms part of Wrangellia's basement.

Both terranes were intruded by the same plutons during the Late Pennsylvanian, between 307 million and 301 million years ago, which made them coeval, but their geologies are otherwise so dissimilar that previous researchers surmised they were unrelated before the Pennsylvanian and had possibly traveled great distances, separately, before accreting to Laurentia.

Now, Steve Israel of the Yukon Geological Survey and colleagues report new data from zircon uranium-lead geochronology and other geochemical analysis from Paleozoic rocks in the Yukon that show the two terranes have likely been linked since the late Devonian, about 363 million years ago, and later were part of the same ancient volcanic arc complex, called the Skolai arc.

"Although the Alexander terrane and Wrangellia are seemingly exotic to Laurentia, we show they are not exotic from one another," the team wrote. "From at least the Late Devonian, the two can be considered as being tectonically and stratigraphically linked."

Sara E. Pratt



The Wrangellia Terrane extends from Vancouver Island, seen here, to central Alaska.
Credit: Keith Freeman, CC BY-SA 2.5

CALIFORNIA: A profusion of drought restrictions with varying results

With 100 percent of California experiencing moderate to exceptional drought conditions last year, according to the U.S. Drought Monitor, Gov. Jerry Brown mandated the tracking of monthly personal water usage for the first time. In addition, water districts around the state also took up varying degrees of drought restrictions, including such strategies as raising water prices and severely limiting outdoor irrigation. But whether these restrictions will make a dent in California's water shortage amid the ongoing and historic drought remains to be seen.

The new monthly reporting requirement, called the residential gallons per capita per day (GPCD), was ordered into effect for one year by the State Water Board last July. GPCD estimates the daily water use by residential customers for almost 400 urban water agencies, representing 35.5 million Californians, more than 90 percent of the state's population.

The order also prohibits all urban California water users from applying potable water to driveways or sidewalks; allowing runoff when irrigating with potable water; using a hose without a shut-off nozzle to wash a car; or using potable water in a fountain or other decorative water feature that doesn't recirculate the water. It also requires urban water suppliers to impose restrictions on outdoor irrigation.

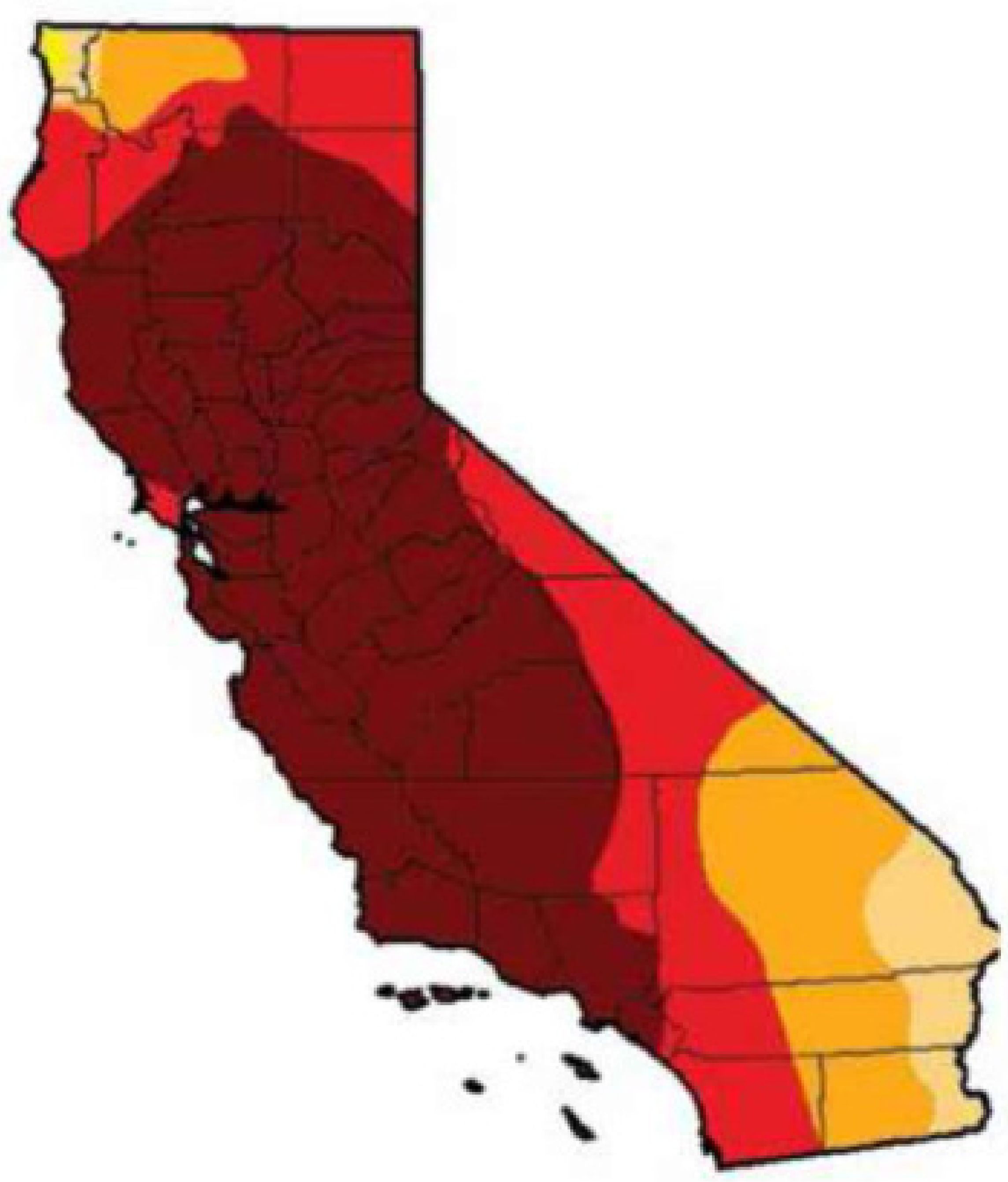
Although these requirements form the basis for the water restrictions enacted by most of the state's urban water suppliers, each urban district's specific restrictions vary widely, resulting in a profusion of drought regulations that have proven difficult for local consumers to follow. To make it easier for consumers, the Association of California Water Agencies mapped the various regulations by district at www.acwa.com/content/drought-map.

These hydroelectric turbines at Oroville Lake in California should be well below water; however, due to the ongoing severe drought, they have been exposed.

Credit: ©Shutterstock.com/David Brimm

U.S. Drought Monitor

California



Dec. 2, 2014

(Released Thursday, Dec. 4, 2014)

Valid 7 a.m. EST

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	99.72	94.42	79.69	55.08
Last Week 11/25/2014	0.00	100.00	99.72	94.42	79.69	55.08
3 Months Ago 9/2/2014	0.00	100.00	100.00	95.42	81.92	58.41
Start of Calendar Year 12/31/2013	2.61	97.39	94.25	87.53	27.59	0.00
Start of Water Year 9/30/2014	0.00	100.00	100.00	95.04	81.92	58.41
One Year Ago 12/3/2013	2.61	97.39	94.15	82.53	27.59	0.00

Intensity:

D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Anthony Artusa
NOAA/NWS/NCEP/CPC

http://droughtmonitor.unl.edu/

As of Dec. 2, 2014, about 94 percent of the state of California was under severe to exceptional drought conditions.

Credit: U.S. Drought Monitor

In addition, each urban water supplier has variously defined stages that increase restrictions as the drought progresses. Stage 1 is usually an alert that notifies the public that a potential water shortage may occur if water demands remain high or dry weather continues. Stage 2 typically enacts mandatory restrictions on outdoor irrigation and often includes increased water prices; Stage 3 is usually triggered by an extreme water shortage and typically includes more aggressive mandatory restrictions and even higher water prices.

Given this patchwork approach, it's not surprising that the conservation results have so far also varied considerably, both within and among regions, according to year-on-year data for September released by the State Water Board in early November.

Because water use varies widely between the cooler, wetter north of the state and the warmer, drier south, the GPCD data can't be compared directly from region to region. In Northern California, for example, the city of Redding, which provides water to about 90,000 customers, cut its GPCD from 255.4 in September 2013 to 208.2 in September 2014, an 18.5 percent decrease. The city has enacted Stage 2 mandatory restrictions, which prohibit exterior watering during the heat of the day and limit it to a maximum of three days per week.

Yet the data show that implementing mandatory drought restrictions is no guarantee of success. The city of Susanville, 180 kilometers east of Redding, has also implemented Stage 2 restrictions, but during the same period, the usage for the population of 9,300 actually increased from 136.2 to 287.6 GPCD, or 111 percent.

In Central California, the 847,000 people served by the San Francisco Public Utilities Commission (SFPUC) averaged 45.7 GPCD, a 9 percent savings compared to the previous September. The SFPUC has invoked Stage 1, requiring its customers to reduce potable water use for outdoor irrigation by 10 percent. Less than 120 kilometers south, the city of Santa Cruz declared a Stage 3 Water Shortage Emergency and in May instituted a water allotment of 249 gallons per person, per day, charging its 95,000 customers higher rates for water consumed beyond that level. Its usage dropped 29.2 percent, from 63.4 to 44.9 GPCD, one of the biggest decreases and lowest usage rates in the state.

Less than half an hour east of Santa Cruz, the city of Watsonville has enacted only voluntary measures, asking for the same 20 percent reduction requested by Gov. Brown in a January 2014 State of Emergency declaration. The 66,000 water customers served by the city have reduced their usage by 14.3 percent, from 113.1 to 96.9 GPCD — a larger drop than many municipalities have achieved with mandatory Stage 2 restrictions.

In Southern California, the Los Angeles Department of Water and Power (LADWP), which serves 3.9 million people, and the city of San Diego, which provides water to 1.3 million customers, have both invoked Stage 2 mandatory restrictions. The LADWP has observed an 8.3 percent drop in water use, from 101.2 to 92.8 GPCD, whereas San Diego's usage, which was lower to begin with, has dropped 3.2 percent, from 84.5 to 81.8 GPCD.

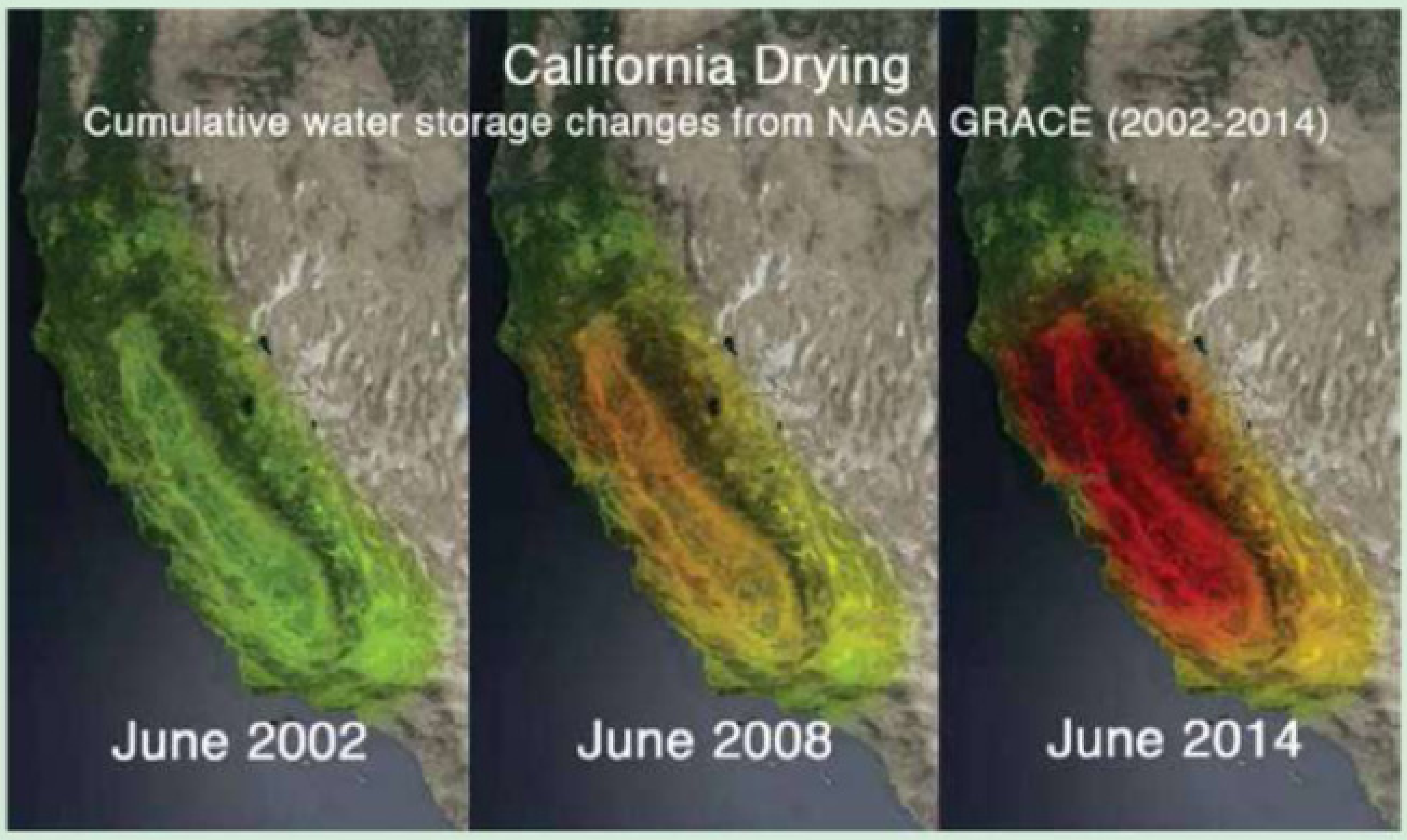
Heavy December rainfall and floods throughout parts of the state did little to relieve the drought and as of late December, most of the same restrictions were still in place.

Terri Cook

California drying out

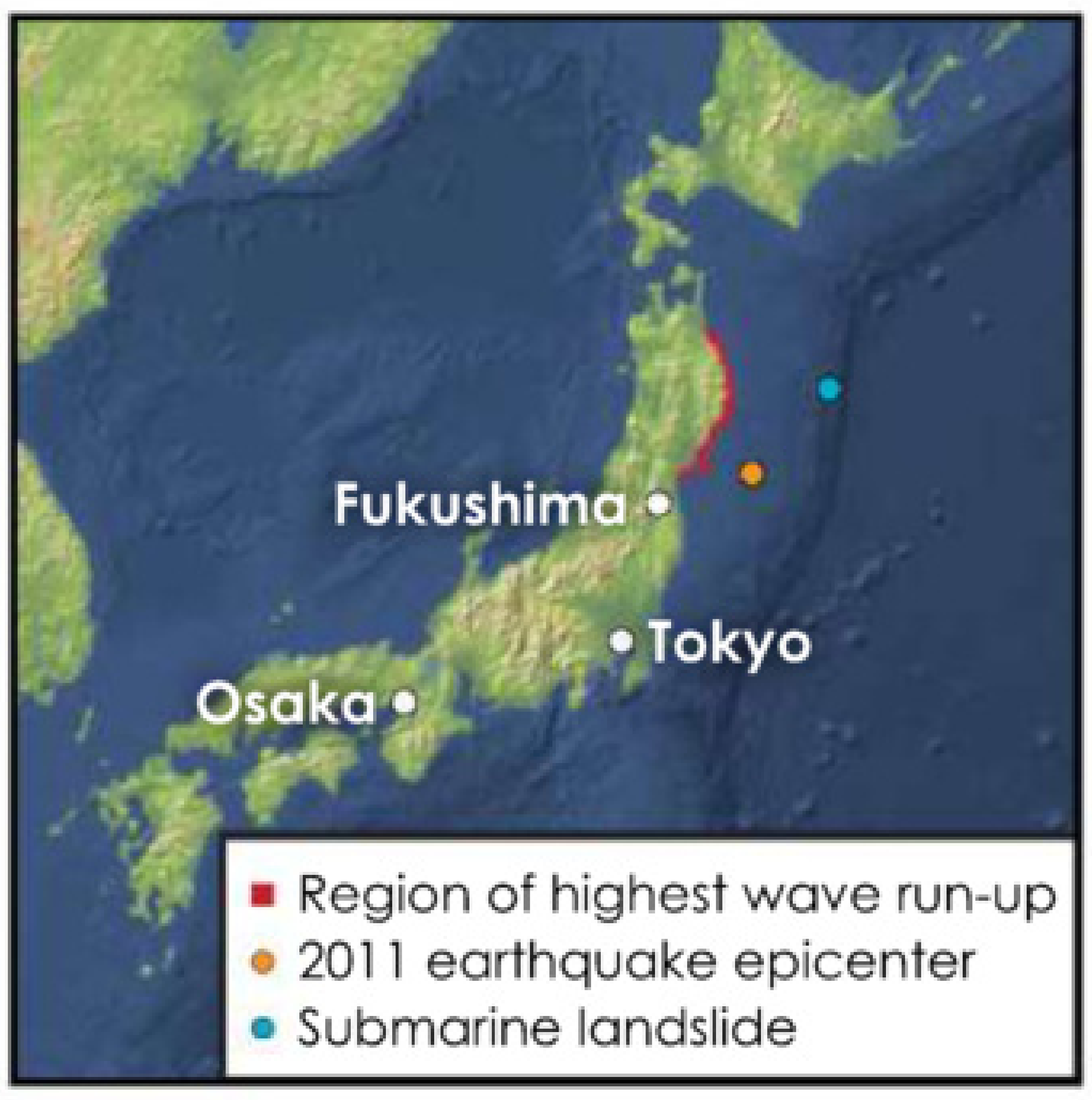
Offering another perspective on the ongoing drought in the western U.S., NASA recently released this three-panel image illustrating relative water loss from California's Central Valley between 2002 and 2014 based on data from the Gravity Recovery and Climate Experiment (GRACE) satellites (hot colors indicate greater loss). The contrast appears greater between the latter two panels, underscoring the substantial impact of recent conditions in California, where 80 percent of the state is facing "extreme" or "exceptional" drought (the two most severe of five drought levels) as of early December, according to the U.S. Drought Monitor. The Sacramento and San Joaquin river basins have lost a combined 15 cubic kilometers of water annually since 2011, partially due to groundwater pumping to sustain agriculture, according to a statement released by NASA.

Timothy Oleson



Credit: NASA/JPL-Caltech/University of California, Irvine

Tohoku tsunami may have gotten a boost from submarine slump



The highest waves during the 2011 Tohoku tsunami occurred about 100 kilometers north of the main rupture.

Credit: Kathleen Cantner, AGI

When the magnitude-9 Tohoku earthquake hit Japan on March 11, 2011, the mainshock triggered tsunami waves averaging about 10 meters in height by the time they reached the coast of Japan, from Fukushima in the south to the northern tip of Honshu Island. But one mountainous stretch of coastline known as Sanriku, about 100 kilometers north of the main rupture area, saw waves higher than 40 meters. This oddity has led some scientists to suggest that a submarine landslide, triggered by the earthquake, may have contributed to the tsunami's extreme height in this region.

Initial investigations attributed the tsunami solely to the mainshock. "However, ongoing modeling suggests that you can't create that wave without additional forcing," says David Tappin, a marine geologist at the British Geological Survey, based in Keyworth, England, and lead author of the new study in Marine Geology.

Additional forcing could have come in the form of a second earthquake, north of the main rupture zone, but seismic records do not seem to show such an event, Tappin says. "So we went looking for evidence of a submarine landslide."

One of the problems with studying submarine landslides is that only a small portion of the seafloor has been mapped in detail, so the chances of having data or images showing what a particular area looked like both before and after an event are slim. "Fortunately, Japan has been acquiring bathymetry data over decades, so were able to do a comparison," he says.

Using bathymetry data collected before and after the 2011 event, Tappin and colleagues identified a slump of displaced sediment 20 kilometers long by 40 kilometers wide and up to 2 kilometers thick that appears to have slid about 300 meters down the slope of the Japan Trench. The slump would have acted like a piston, pushing a wall of water toward the Sanriku coastline and increasing the height of the tsunami waves in that region, he says.

But not everybody is convinced that a landslide occurred. "We conducted seismic imaging of the seafloor structure last year in the same area discussed by this paper, but we could not find any strong evidence of a large landslide in this area," says Shuichi Kodaira, a geophysicist at the Japan Agency for Marine-Earth Science and Technology in Yokohama who was not involved in the new study.

The discrepancies between the findings from Tappin's team and those of Japanese researchers may be due to uncertainties inherent in bathymetric mapping. "Seafloor mapping requires very precise mathematical corrections to reduce uncertainty. As far as I can tell, this group did not make such data processing corrections before doing their analysis," Kodaira says.

Tappin and his colleagues plan to conduct additional mapping of the seafloor in the same region using multibeam bathymetry methods, in hopes of better defining the slump. "We're seeking to validate the results of our modeling and observations by investigating the marine environment in more detail."

So far, "most Japanese scientists have not accepted an additional source for the tsunami," Tappin says. "Right now, we're trying to persuade them to acquire more data."

Mary Caperton Morton

Plate tectonics seen on Europa

Credit: Noah Kroese, I:NK

Earth is no longer the only body in the solar system where plate tectonics operates, according to new research reported in Nature Geoscience. Jupiter's moon Europa has moving crustal plates too, but the plates are made of ice instead of rock. Simon Kattenhorn of the University of Idaho and Louise Prockter of Johns Hopkins University's Applied Physics Laboratory found evidence in images taken by the Galileo spacecraft of subduction-zone-like features where huge slabs of rigid surface ice appear to be subsumed into a thick layer of warmer ice below. Along with existing indications of strike-slip faulting and extensional features similar to Earth's mid-ocean ridges, the results suggest Europa has all the necessary ingredients for plate tectonics.

Timothy Oleson

Ancient cave art discovered in Indonesia

Europe has long been thought to have been the home of the oldest art in the world — including a stash of cave paintings in northern Spain that date to about 40,000 years ago — but a new dating technique may put Indonesia on the ancient art map as well.

A dozen hand stencils and two figurative animal illustrations were originally discovered in the 1950s in a series of caves on the island of Sulawesi. For decades, the paintings were assumed to be about 10,000 years old because of the rapid rates of erosion of the area's limestone rocks. But microscopic samples of the "cave popcorn" covering some of the artwork have revealed that the oldest images — stencils of a splayed human hand — are about 40,000 years old. A depiction of a babirusa, or pig-deer, was dated to at least 35,400 years old, making it one of the oldest figurative depictions in the world.

The find helps fill in the long-mysterious geographical gap between ancient cave art in Europe and in Australia, where Aboriginal paintings have been dated to about 30,000 years ago and red ochre crayons have been dated to about 50,000 years old. "Among the implications, it can now be demonstrated that humans were producing rock art by about 40,000 years ago at opposite ends of the Pleistocene Eurasian world," the authors, led by Maxime Aubert of Griffith University in Australia, wrote in Nature.

Mary Caperton Morton

Stencils of a splayed human hand in an Indonesian cave date to about 40,000 years ago.
Credit: Kinez Riza

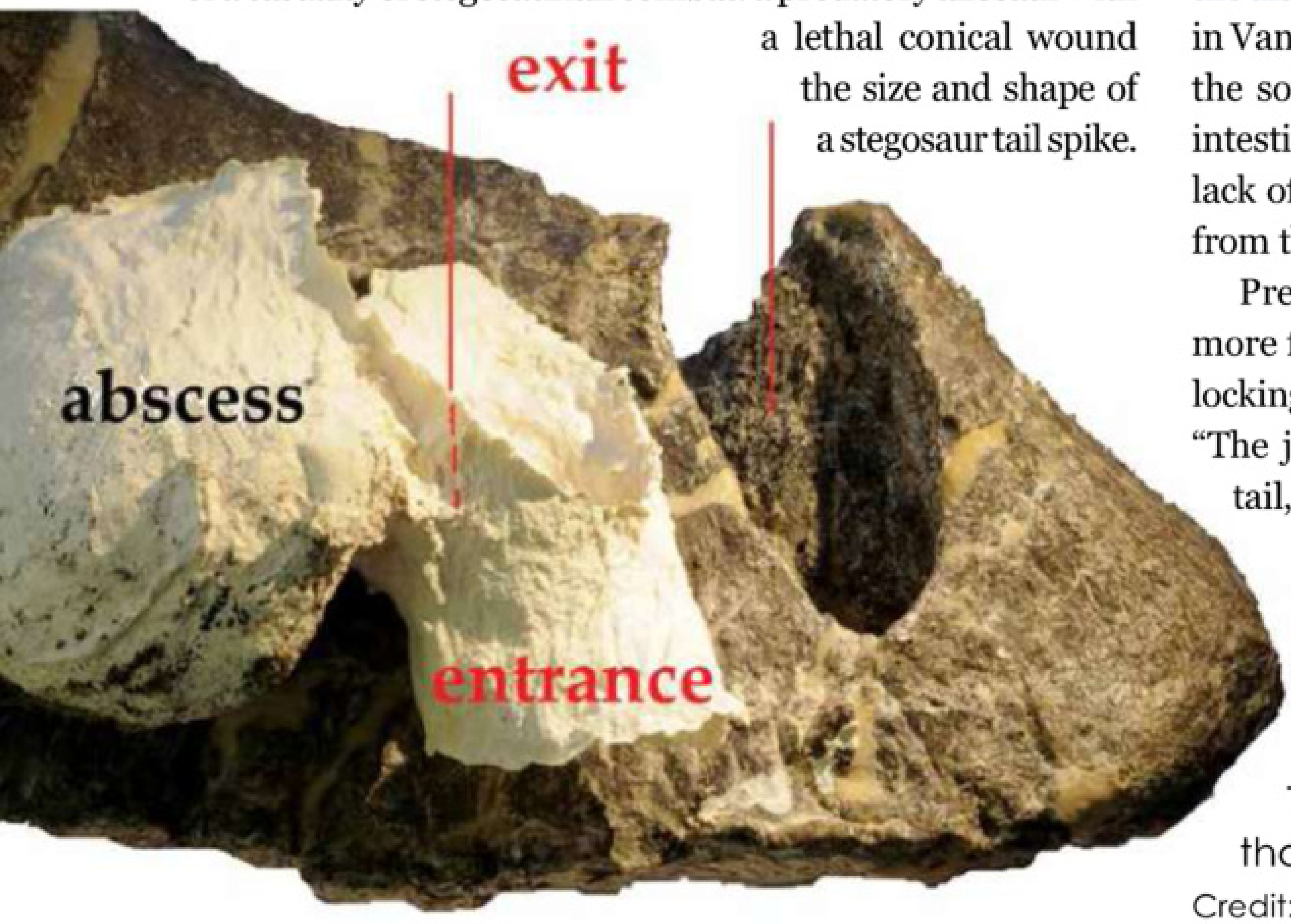
Stegosaur's tail packed a lethal punch

With their big lumbering bodies and plates of armor, stegosaurs can be likened to the modern-day rhinoceros. Both are primarily peaceful plant eaters, but you wouldn't want to make either of them mad. Now, paleontologists have uncovered evidence of a casualty of stegosaurian combat: a predatory allosaur with a lethal conical wound the size and shape of a stegosaur tail spike.

The stab wound was found in the pubis bone of the allosaur, a place that would have taken great dexterity on the part of the stegosaurus to reach. "A massive infection ate away a baseball-sized sector of the bone," said Houston Museum of Natural Science paleontologist Robert Bakker, who presented a poster on the discovery at the annual Geological Society of America meeting in Vancouver, B.C. "Probably this infection spread upwards into the soft tissue attached here, the thigh muscles and adjacent intestines and reproductive organs," he said in a statement. The lack of any signs of healing strongly suggests the allosaur died from the infection, he said.

Previous discoveries have hinted that stegosaurs' tails were more flexible than other dinosaur tails of similar size, with no locking joints and massive muscles at the base of the appendage. "The joints of a stegosaur tail look like a monkey's [flexible] tail," Bakker said. Stegosaur tails "were built for 3-D combat."

Mary Caperton Morton



The stegosaur tail spike entered the allosaur's pubis and passed all the way through the bone. The wound then led to an abscess and infection that eventually spread and killed the allosaur.
Credit: Robert Bakker

New tracers can identify fracking fluids

Water tanks onsite near a hydraulic fracturing operation.

Hydraulic fracturing to harvest natural gas has been controversial due in large part to the potential for contamination of ground and surface waters by the pressurized fluids used to force open cracks in deep shale formations and by the so-called flowback fluids that re-emerge at the surface from fracking wells. Now, researchers have developed a geochemical method of tracing fracking fluids in the environment; it's a tool that could be used to identify hazardous spills in the future and may lead to better use and disposal of fracking wastewater.

Fracking involves pumping mixtures of water, sand and chemicals underground at high pressures to crack open conduits through underground reservoirs of natural gas. The gas then flows up to the surface where it can be collected, along with the fracking fluids. Most of this fluid is captured in storage containers, but occasional spills and accidents mean that portions of the flowback fluid can find their way into the environment. And tracking the fluids through the environment has proved difficult, due to the proprietary nature of the mixtures.

"Developing tracers for fracking fluids has been tricky, given that the chemistry of fracking fluid is not usually revealed. It's a trade secret," says Avner Vengosh, a geochemist at Duke University and co-author of a study describing the new tracing technique, published in Environmental Science & Technology.

A handful of tracing techniques have been developed to date, including DNA-based tracers, but those methods usually require adding tracers to fracking fluids before they are injected. Other tracing methods cannot distinguish between fracking fluids and contaminated water generated by conventional oil and gas exploration.

In order to develop a better tracking technique, Vengosh and colleagues spent years building a database of the compositions of fracking fluids used by various companies in different shale environments from New York to Arkansas. "Getting samples for characterization was not easy. In many cases we were working with landowners who had found spills on their property after drilling operations," Vengosh says.

Once the researchers assembled what they considered an "extensive" dataset – 15 samples of hydraulic fracturing flowback fluids – the team set about characterizing the fluids, looking for shared chemistries that could be used to fingerprint the fluids. They found that fracking fluids have distinctive isotopic ratios of boron and lithium, which are found naturally in clay minerals within the shale formations. As the fracking fluids react and mix with clays deep underground, they become enriched in boron and lithium. When the fluids return to the surface, they have distinctive isotopic fingerprints that are different from other types of wastewater, including wastewater from conventional gas or oil wells, as well as from naturally occurring background water.

So far, Vengosh and colleagues have tested their method at a fracking fluid spill site in West Virginia and downstream from an oil and gas brine wastewater treatment plant in Pennsylvania, both documented in the study. Using the tracers, the team determined where fracturing fluids had been released in the environment.

Ultimately, the researchers say that they hope the method will be used to identify ways to improve how shale gas wastewater is treated and disposed. "We're being very careful, but we think we have a universal tool to identify the source of contamination and link to fracking fluid," Vengosh says.

The development of a tracer for fracking fluid is a "critical step" in studying and regulating the use and disposal of fracking fluids, says Brian Lutz, a biogeochemist at Kent State University in Ohio who was not involved in the new research. "This seems like a very robust method because the isotopes can be detected at very low concentrations," he says, meaning the method has "impressive power to identify small levels of contamination by volume in freshwater."

The isotopic ratios of lithium and boron that the team found are also consistent across the fracking fluid samples from different shale environments, indicating the method may work in a wide range of places, Vengosh says. That's an important feature, as fracking is currently taking place in a number of different geologic settings from New York to Texas to Nebraska to British Columbia.

However, the tracing method may end up fanning the controversy over fracking rather than quelling it, Lutz says. "It's critical to be able to detect contamination, but it's also important to continue to study the impacts of that contamination on human and environmental health," Lutz says. "Just because you can detect fracking fluids in a place doesn't mean they're toxic."

Mary Caperton Morton

Scientists sequence oldest modern human genome to date

A chance fossil find along a Russian river has provided researchers with the oldest genomic data ever sequenced from a modern human. The fossil, a nearly complete left femur, was pulled from a bank along the Irtysh River near the Ust'-Ishim district in western Siberia in 2008 by a Russian artist before it made its way to scientists.

The Ust'-Ishim femur belonged to a modern human man who lived in western Siberia roughly 45,000 years ago.

Credit: Bence Viola, MPI EVA

Radiocarbon dating, isotopic studies and genomic sequencing revealed that the bone belonged to a male who subsisted on a hunter-gatherer's diet of plants and meat about 45,000 years ago. In addition to offering the oldest modern human genome studied, the find represents the oldest modern human from outside of Africa and the Middle East to be radiocarbon dated.

An international team led by Svante Pääbo and Janet Kelso of the Max Planck Institute in Germany reported in Nature that about 2 percent of the Ust'-Ishim genome had come from Neanderthals — roughly the same proportion that is seen in modern Eurasians. However, the lengths of the residual Neanderthal segments are longer than those found in populations today and in more recent fossil humans, attesting to the Ust'-Ishim man's closer ties to ancestors who had mated with Neanderthal neighbors.

Based on comparisons of their results to existing fossil finds and prevailing theories for early modern human expansions, the team suggested that the Ust'-Ishim individual was likely related to "an early modern human radiation [from Africa roughly 50,000 years ago] into Europe and Central Asia that may have failed to leave any descendants among present-day populations." This radiation may have been distinct, they noted, from other, previously proposed migrations.

Timothy Oleson

Crumbly amber holds dinosaur secrets

In the movie "Jurassic Park," dinosaurs were resurrected from DNA in blood harvested from Mesozoic mosquitoes preserved in amber. The plot was pure science fiction, but a new study has found another use for the biological material trapped in fossilized tree resin. By studying microscopic inclusions of plant material, pollen and feathers preserved in bits of amber recovered alongside dinosaur fossils, paleontologist Ryan McKellar of the Royal Saskatchewan Museum in Canada is recreating a more complete picture of the Mesozoic landscape.

"Basically it puts a backdrop to these dinosaur digs, it tells us a bit about the habitat," McKellar said in a statement. The amber can reveal details such as what kinds of plants and insects were abundant, and what the atmosphere was like at the time the amber was formed. For example, the study, presented at the 2014 Geological Society of America Annual Meeting in Vancouver, B.C., details the discovery of an aphid coated in amber, found stuck to fossilized remains of a duck-billed dinosaur. The insect can't be used to build a new duckbill, but it can reveal information about the evolution of insects and their ecological relationship to dinosaurs. "When you get insects, it is like frosting on the cake — you can really round out the view of the ecosystem," McKellar said.

McKellar uses tiny bits of friable amber — found in conjunction with fossil-rich bone beds — which crumbles more readily than the familiar jewelry-grade variety of amber. Working with friable amber was difficult until recently, but McKellar's technique reduces crumbling by vacuum-injecting the amber with epoxy.

Insects preserved in amber can't be used to reengineer dinosaurs, but they can reveal details of Mesozoic habitats.

Credit: University of Alberta Strickland Entomology Museum specimen, R.C. McKellar

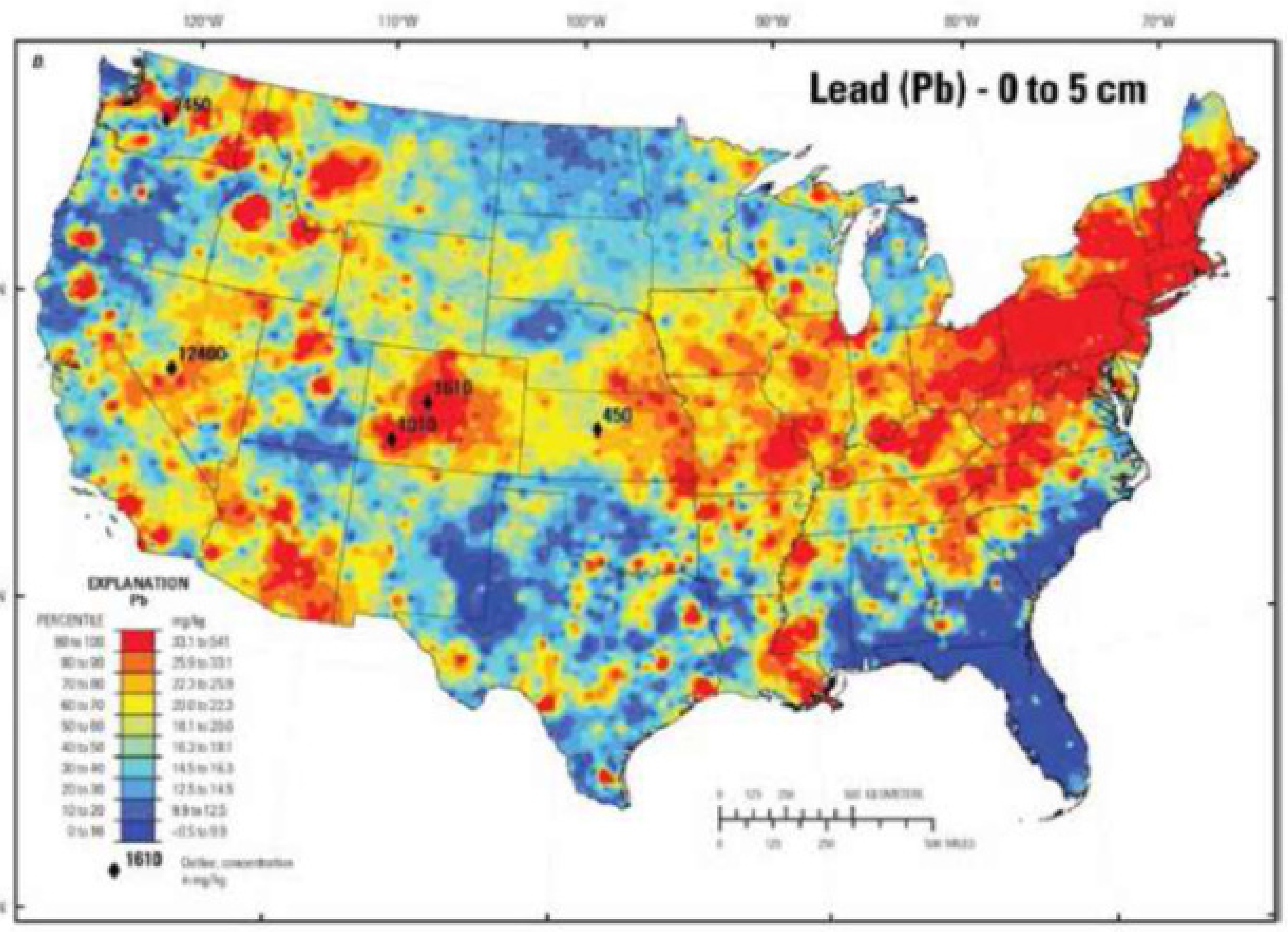
Friable amber is widespread across North America and commonly found in association with coal and bone beds.

Mary Caperton Morton

New nationwide soil map available online

The U.S. Geological Survey (USGS) recently completed a seven-year soil-mapping project detailing the mineralogy and geochemistry of soils across the lower 48 U.S. states. Bill Cannon, an emeritus scientist at the USGS in Reston, Va., and co-author of the report, which was published in 2014, discussed the effort last October at the Geological Society of America's annual meeting in Vancouver, B.C.

Sampling was conducted at 4,857 sites — one per 1,600 square kilometers — and at each site, soil samples were collected at three depths: from the surface layer down to 5 centimeters depth, from the "A horizon" or topsoil beneath the surface layer, and from the "C horizon," which consists largely of bedrock regolith. Samples were then tested for their mineralogy and for 45 major and trace elements. The new data provide "an estimate of the abundance and spatial distribution of chemical elements and minerals in soils of the conterminous United States and represent a baseline for soil geochemistry and mineralogy against which future changes may be recognized and quantified," according to the report's abstract.



Lead concentrations in the surface layer of soil across the U.S., based on data from a new U.S. Geological Survey report.
Credit: U.S. Geological Survey

Along with the report, which presents the results in detail, USGS has created an interactive website where visitors can view data of interest — the abundance of lead in the surface soil layer, for example — overlaid on a U.S. map. Statistics for each dataset are available for display, and users can export data to Google Earth and create PDFs or images of customized maps.

Paraphrasing the science writer Deborah Blum, the report authors wrote: "The data aren't so fine that they will tell you what lies in your backyard behind the raspberry bush; however, they will show you the metal and mineral patterns that color your part of the world and they will remind you — as they should — of the astonishing and diverse chemistry that the planet creates under our feet."

Timothy Oleson

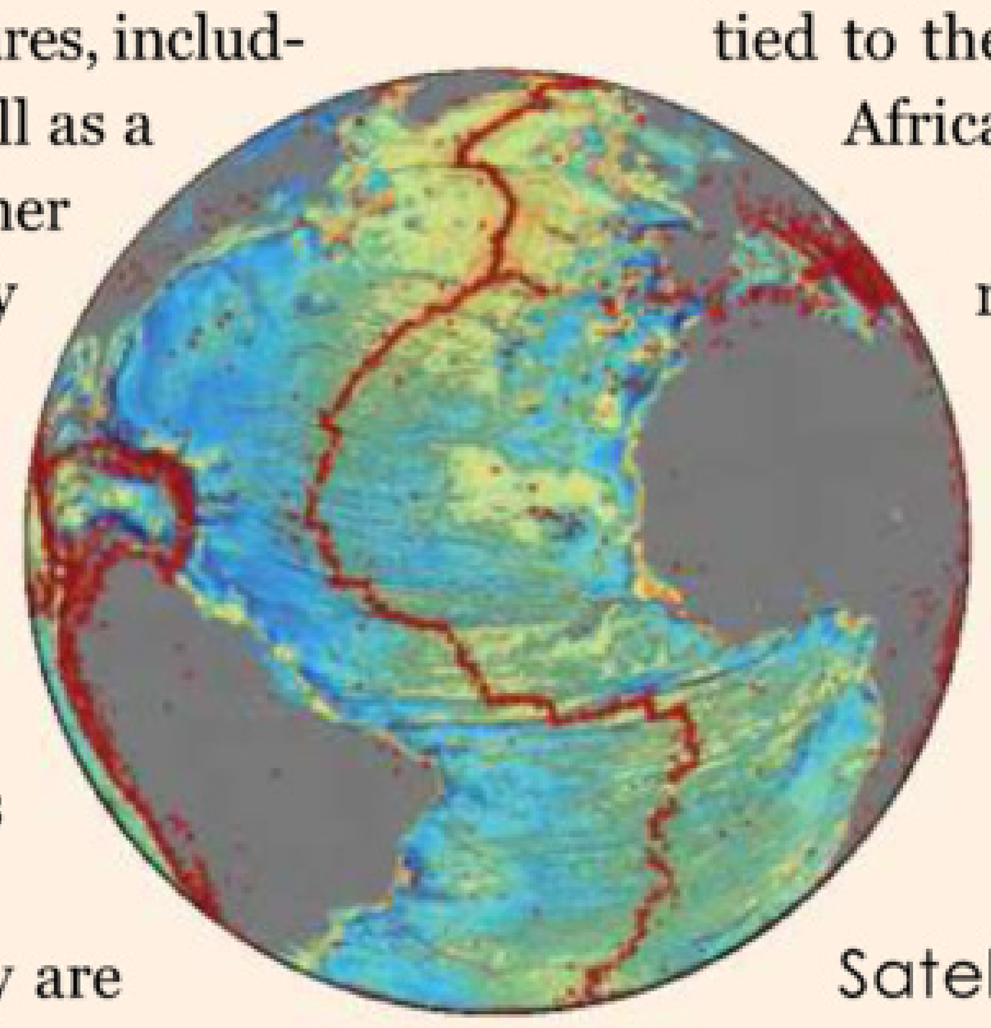
Wealth of seafloor features emerges from new survey

A new survey of Earth's deep ocean — 80 percent of which remains unmapped — has revealed a wealth of previously unknown features, including thousands of seamounts as well as a variety of undersea tectonic features that are either buried under too much sediment or were simply too small to be seen before. Researchers led by geophysicist David Sandwell of the Scripps Institution of Oceanography used high-resolution altimetry data from two Earth-observing satellites to produce a global marine gravity model that the team described in Science as twice as accurate as earlier incarnations.

Among the features seen in the new survey are numerous ridges, fracture zones and abyssal hills, many of which are buried under kilometers of sediment that have long obscured them from satellite observations, the team reported. In particular, they described a previously unobserved extinct spreading ridge in the Gulf of Mexico and new features tied to the opening of the Atlantic Ocean between Africa and South America.

The study, which benefitted from advancements both in remote sensing and data analysis, should help improve seafloor mapping and produce more accurate plate tectonic reconstructions, thus offering insight into what Earth looked like in the past, the researchers suggested.

Timothy Oleson



Satellite altimetry data have revealed numerous never-before-seen seamounts and other undersea features.
Credit: David Sandwell, Scripps Institution of Oceanography

Ice (Re)Cap

From Antarctica to the Arctic; from polar caps, permafrost and glaciers to ocean-rafted sea ice; and from burly bears to cold-loving microbes, fascinating science is found in every nook and crevasse of Earth's cryosphere, and new findings are announced often. Here are a few of the latest updates.

- Water that collects at the base of glaciers during the warm melt season lubricates movement of the ice over the ground beneath. But many aspects of this process — including how meltwater modulates glacial velocities on daily and seasonal timescales — remain unclear. In a new study in Nature, Lauren Andrews of the University of Texas at Austin and colleagues have helped illuminate the effects of subglacial hydrology on ice velocities in the Paakitsoq region of western Greenland.

  The team measured water pressures in large naturally occurring cavities called moulins — which funnel meltwater from a glacier's surface to networks of drainage channels at its base — as well as in boreholes drilled through the ice into areas of the base not directly connected to the drainage channels. They then compared the pressures with GPS measurements of ice velocity. The team found that pressure changes in the moulins, which correspond to increases or decreases in meltwater flow through the drainage channels, correlated with daily changes in ice velocity. A previously observed but unexplained longer-term slowdown of glacial velocities late in the melt season correlated, on the other hand, with pressure drops in the areas unconnected to the channels. The findings show that changing meltwater drainage both from the "unchannelized" portions of the glacier as well as from the channels impacts ice movement, the researchers wrote, and that a more nuanced picture of glacial undersides is necessary to understand their behavior.

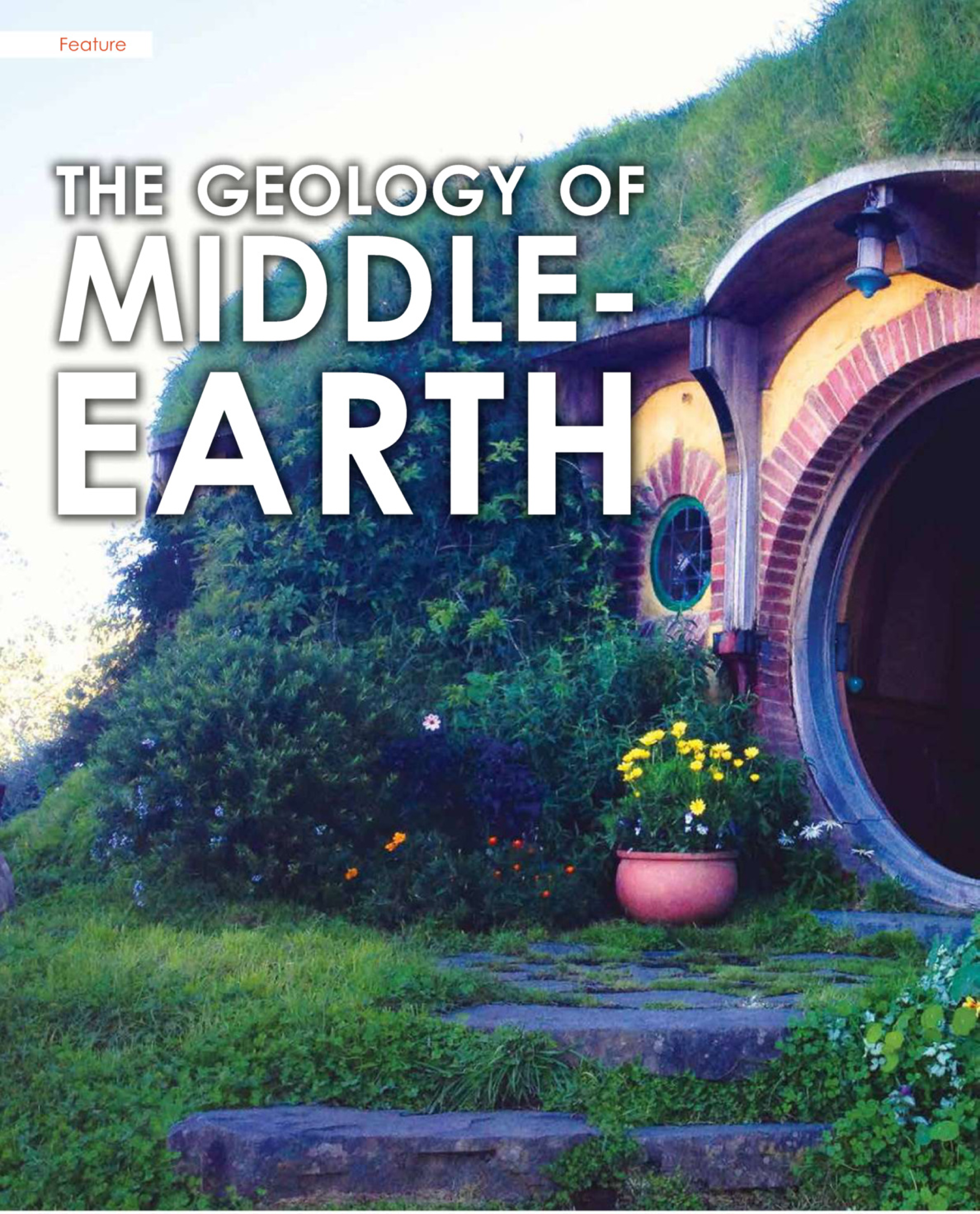
- The likelihood of severe winters in central Eurasia, including parts of China, Kazakhstan, Mongolia and Russia, is roughly twice what it was several decades ago, according to a new study in Nature Geoscience. Masato Mori of the University of Tokyo in Japan and colleagues simulated atmospheric conditions over Europe and Asia, considering variable levels of sea ice in the Barents and Kara seas. They found that as sea-ice levels declined, the region was more prone to so-called "blocking" wind patterns that pulled cold Arctic air farther south than normal for extended periods. The new modeling supports earlier observational studies that have correlated recent cold winters in Eurasia with dwindling sea ice. However, the researchers reported, as sea-ice levels continue to drop, the increased odds of harsh winters may abate toward the end of this century.

Surface meltwater from the Greenland Ice Sheet pours into a moulin, emptying into a network of drainage channels at the base of the glacier.
Credit: Lauren Andrews

- Figuring out why the glaciers of the Karakoram Mountains — which range over portions of western China, northern India and northern Pakistan — appear to be holding steady or perhaps even growing in size while most of the world's mountain glaciers are shrinking has been difficult, given the region's remote, rugged terrain. Now, scientists using a high-resolution climate model along with meteorological observations to investigate the Karakorams, as well as areas of the nearby Himalayas and Tibetan Plateau where glaciers are losing mass, may have figured out why. In Nature Geoscience, Sarah Kapnick of Princeton University and colleagues reported that whereas the Himalayas receive most of their annual precipitation as rain during the summer monsoon season, the Karakoram region receives the majority of its precipitation in the winter, meaning it falls as snow and feeds the glaciers there. This meteorological distinction "uniquely protects [the Karakorams] from reductions in annual snowfall under climate warming," the researchers wrote.

Timothy Oleson

THE GEOLOGY OF MIDDLE-EARTH



Hobbiton, a village near Matamata, New Zealand, was created for "The Lord of the Rings" movies.
Credit: ©CedricSF, CC BY-NC 2.0

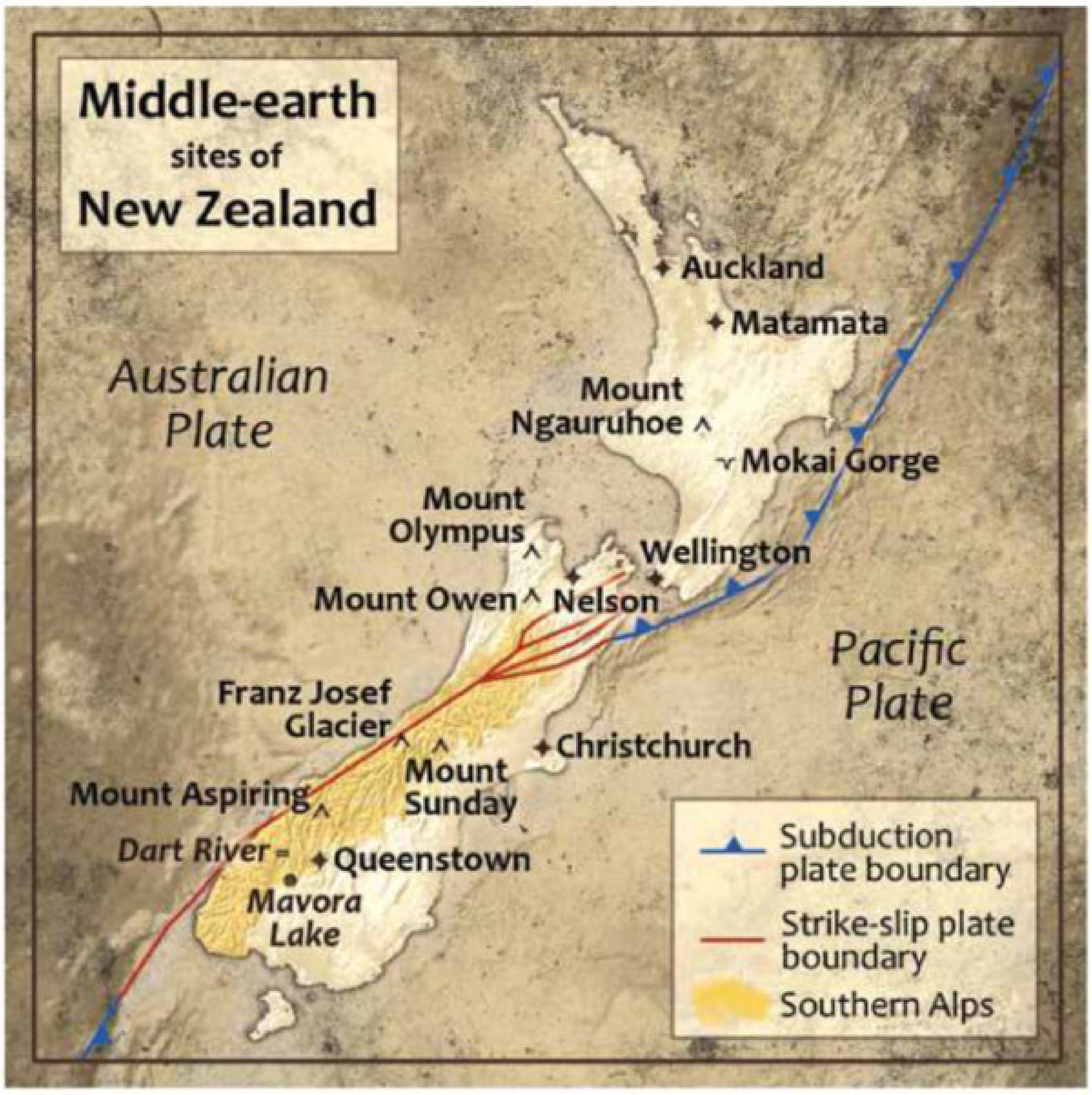
Terri Cook

The first time filmmaker Peter Jackson read J.R.R. Tolkien, he was 18 years old and riding a train across the North Island of his native New Zealand. Whenever Jackson glanced out the train's window, he was struck by how much the passing landscape resembled his imagined picture of Tolkien's mythical realm of Middle-earth. This revelation stuck with him; two decades later, Jackson chose New Zealand as the backdrop for his blockbuster film adaptation of the entire "The Lord of the Rings" trilogy, and again later when filming "The Hobbit" series.

This landscape — with its vaguely familiar, yet primeval feeling — was integral to creating the atmosphere and evoking the emotion of Tolkien's fabled world set 6,000 years ago on Earth. Who can forget Aragorn galloping toward the isolated, windswept grandeur of Edoras, the capital of the Kingdom of Rohan, or an exhausted Frodo Baggins stumbling across the dark, threatening moonscape of Mordor? Thanks to Jackson and his production team, Tolkien's Middle-earth will forever be associated with New Zealand's breathtaking landscapes.

Just as enthralling as Tolkien's mythical prehistory is another, considerably longer epic tale of the geology of this landscape, which formed over hundreds of millions of years.

Since the release of "The Fellowship of the Ring" in 2001, millions of tourists have flocked to the Southern Hemisphere to see "The Lord of the Rings" movie backdrops for themselves. As an avid Tolkien fan, I too wished to follow in the Hobbits' hairy footsteps and visit a few of the key filming locations while also learning more about the formation of the "real" Middle-earth.



Locations of some of the 100 filming sites in New Zealand that stood in for mythical MIddle-earth locales in "The Lord of the Rings" movies.
Credit: Kathleen Cantner, AGI

A Sliver of Gondwana

Much of Middle-earth's natural history is interwoven with the story of Gondwana, the southern part of Pangaea, which broke away about 200 million years ago. The supercontinent of Gondwana included most of modern-day Africa, India, South America, Antarctica, Australia and New Zealand. The bulk of New Zealand's landmass was formed along Gondwana's east coast where, over millions of years, ash belched by offshore volcanoes and thick piles of sediment deposited by rivers draining the continent's interior accumulated in the sea. Repeated mountain-building episodes uplifted and plastered these new rocks onto the edge of the expanding supercontinent.

As Gondwana subsequently broke apart, the mostly submerged micro-continent of Zealandia, of which New Zealand is a small part, began to rift away from Australia and Antarctica about 85 million years ago. New Zealand has endured noteworthy isolation ever since, resulting in the evolution of a unique fauna and flora, including species descended from ancient Gondwanan ancestors in the country's dense temperate rainforests, which endow the countryside — and Jackson's Middle-earth — with its primeval feeling.

Today the inexorable forces of plate tectonics are still sculpting New Zealand's landscape, forging the fabulously diverse scenery that Jackson harnessed to recreate the various moods and geographies of Middle-earth. Such great diversity over an area about the size of Colorado is the direct result of New Zealand's modern position straddling the boundary between two major tectonic plates, the Australian and the Pacific.

In the current configuration, New Zealand's North Island rests entirely on the Australian Plate and hosts many volcanic features — including steaming hot springs, geysers, and a chain of active volcanoes such as Ngauruhoe, the model for Mount Doom — created by the subduction of the Pacific Plate off the island's east coast. In contrast, most of the South Island lies on the Pacific Plate. Here, the plate boundary runs along the island's west coast and is defined by a major strike-slip fault, the Alpine Fault. There is also compression along this boundary that is uplifting the Southern Alps, the breathtaking stand-in for Tolkien's Misty Mountains.

The Misty Mountains

All three "The Lord of the Rings" movies were filmed simultaneously, an unusual step for live-action filmmaking. From the beginning Jackson and producer Barrie Osborne committed to filming in the best — rather than the easiest — locations, according to "'The Lord of the Rings' Location Guidebook" by Ian Brodie.

Selecting the filming sites for the $280 million production was a long and meticulous process. First, a team delved deeply into Tolkien's vivid descriptions, assembling lists of the attributes their filming locations must have to recreate each Middle-earth locale. Conceptual artists then transformed Tolkien's eloquent words into detailed drawings, which scouts carried into the bush, crisscrossing the country to identify matching sites.

After this initial sweep, Jackson and Osborne led a team to visit each potential locale, questioning first and foremost if the locations matched Tolkien's descriptions. They also examined logistical challenges posed by each area before settling on sites. This process was only the beginning of a monumental effort; the production ultimately involved more than 100 locations, 300 sets and 2,500 cast and crew members spread across the two islands.

Many of the most memorable scenes from "The Lord of the Rings" trilogy were filmed amid the South Island's Southern Alps, where compression

Several movie scenes were filmed near the Franz Josef Glacier, which terminates less than 300 meters above sea level on the South Island's west coast.

Credit: above: ©Rachael Taft, CC BY-ND 2.0; right: ©Anthony Cramp, CC BY 2.0

along the Alpine Fault is actively uplifting ancient basement rocks, predominantly dark greywacke sandstone, plus schist, gneiss and granite.

In the films, the Southern Alps stand in for the Misty Mountains, Middle-earth's lofty, snow-capped range towering above rolling, grassy plains. In Tolkien's mythology, the 1,500-kilometer-long range was uplifted in the First Age and contained Middle-earth's highest peaks, including Caradhras, on whose slopes the struggling Fellowship tried to cross the divide. The orographic lift and ensuing clouds and precipitation created by strong westerly winds gave the mythical mountains their name, and the same conditions prevail in the real Southern Alps today, which posed many challenges during the filming.

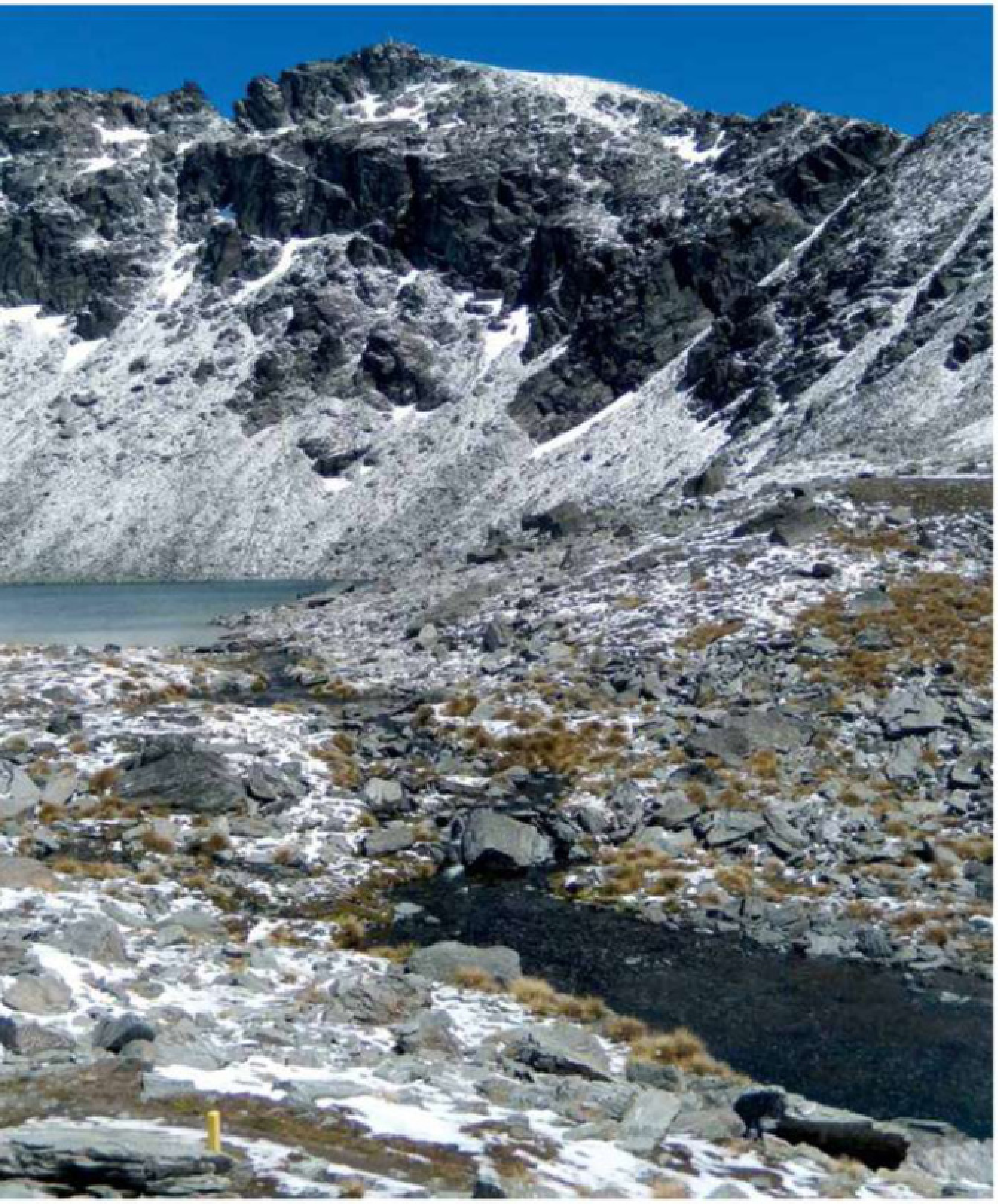
The Misty Mountains' spectacular peaks are featured in the opening sequence of the second movie, "The Two Towers," filmed near the real Mount Aspiring, and in the Lighting of the Beacons in the third film, "The Return of the King." During this succession of igniting mountain-top flares, you can see some of the Southern Alps' dark basement rocks. These scenes were filmed near the real Mount Gunn in Westland National Park near the heavily crevassed Franz Josef Glacier. For Tolkien fans with deep pockets, both of these filming areas are accessible via special helicopter tours.

Many of the most memorable scenes from the trilogy were filmed amid the South Island's Southern Alps, which are composed mostly of dark greywacke sandstone and are visible in a number of scenes.

Credit: above: Terri Cook and Lon Abbott; right: ©Shutterstock.com/Sam DCruz

The production team often filmed single movie scenes in multiple locations and then spliced them together to create the perfect ambience, albeit at the cost of geologic congruity. For example, the karst of Mount Owen (above) was mixed with the dark schist found near Lake Alta (below), 500 kilometers away, to create the mythical Dimrill Dale.

Credit: above: ©Dru, CC BY-NC 2.0; below: Terri Cook and Lon Abbott



The Dimrill Dale

One of the trilogy's most poignant scenes occurs in the mythical Dimrill Dale, a valley on the eastern side of the Misty Mountains, where the Fellowship mourns the death of their companion, the wizard Gandalf. The characters' heartbroken expressions and the Hobbits' forlorn sobs seem to be amplified by the surrounding stark, white, pockmarked landscape — a great example of how Jackson and his team used New Zealand's geology to enhance the emotion of a scene. Jackson often filmed the same scene in multiple locations and spliced the results together to create the perfect ambience — albeit at the cost of geologic congruity.

The upper Dimrill Dale, for example, was filmed on Mount Owen in the South Island's Kahurangi National Park, located west of the city of Nelson. This area, part of the small chunk of the Australian Plate on the island's northwestern corner, is locally capped with Ordovician white marble, which rainwater has partially dissolved, gradually enlarging fractures and cavities. Continued dissolution has produced karst, the distinctive, pitted topography full of sinkholes apparent in this scene. Yet seconds later, as Aragorn leads the group down the valley, he runs through a stream surrounded by talus piles of dark, angular rocks. This portion of Dimrill Dale looks completely different, and for good reason: Instead of white marble, it features dark schist that's found on a different tectonic plate. These scenes were captured at the real Lake Alta above the Remarkables Ski Field near Queenstown, about 500 kilometers to the south.

Two other sites in the Nelson area were also used in "The Fellowship of the Ring." The first was Takaka Hill — which is located not far from Harwood's Hole, the largest sinkhole in the Southern Hemisphere — which stands in for a grass-covered limestone plateau near the wilderness of Chetwood Forest, where Aragorn led the Hobbits after they left Bree.

The second was Mount Olympus, a mid-Cretaceous granite pluton that Jackson used to portray some of the rough country to the south of the mythical Elven city of Rivendell. Here among spectacular real-life 110-million-year-old granite spires, the Fellowship hid from Saruman's spying black crows. Part of a series of four plutons, this granite is the root of an ancient volcanic arc created by subduction along the edge of Gondwana while New Zealand was still attached. The granite was later added to the landmass during a violent mountain-building collision.

Visitors can tour the hobbit holes in Hobbiton.
Credit: ©Chris, CC BY-ND 2.0

The town of Nelson, renowned for both its sunshine and its artisans, is where the props department for the "The Lord of the Rings" procured many important articles, including 50 copies of the One Ring crafted by silversmith Jens Hansen and his son, Thorkild. One of the originals is still on display at their shop (where visitors can buy a replica of their own in 9- or 18-karat gold).

Tolkien fans who, like a Hobbit, are always ready to eat a "second breakfast" or drink a pint of ale should be sure to visit nearby Harrington's Breweries, which concocted a special stout beer that was served at the pubs in the Tolkien towns of Hobbiton (Matamata) and Bree during filming. Because of the number of takes required to shoot scenes, the ale's alcohol content was limited to 1.1 percent. Happily, the brewers also created a more potent version for visitors who, like Merry and Pippin, like to sing and dance on the tables.

The 110-million-year-old granite spires of Mount Olympus provided one of the most distinctive backdrops in the trilogy.
Credit: ©iStockphoto.com/HowardPerry

In the town of Nelson, visitors can buy a replica of the One Ring in 9- or 18-karat gold at Jens Hansen's shop.
Credit: Terri Cook and Lon Abbott; inset: ©Jerry Kan Chen, CC BY-NC-ND 2.0

The longest river in Middle-earth, the Anduin, was portrayed in the films by a composite of multiple New Zealand rivers, including the Kawarau.
Credit: Terri Cook and Lon Abbott

The River Anduin

More than 2,000 kilometers long and flowing parallel to the Misty Mountains, the Anduin is the longest river in Middle-earth. After leaving the peaceful forest of Lothlórien, the Fellowship followed the Anduin's course for days, paddling Elven boats nearly 500 kilometers down the river's iridescent blue waters.

In "The Fellowship of the Ring," Jackson's version of the Anduin was a composite of five different rivers that collectively highlight New Zealand's scenic and geologic diversity. The impressive 80-meter-deep Mokai Gorge on the North Island's Rangitikei River, near Taihape, was the first to appear on screen. Additional shots were filmed on one of its tributaries, the fern-draped Moawhango River. In the Wellington area of the North Island, close-up footage of the Fellowship paddling their boats was filmed on the beautiful Hutt River.

The Hutt River follows the trace of the active Wellington Fault, a predominantly strike-slip feature that runs along the west side of Wellington's harbor (itself a volcanic caldera) and forms Hutt Valley's unusually straight western edge. In 1855, a major earthquake on the nearby Wairarapa Fault raised the level of both the riverbed and the valley, draining the surrounding wetlands and leaving the previously navigable river impassable.

On the South Island, additional River Anduin scenes were filmed on the Waiau River, which flows between two beautiful lakes that formed in deep, glacially carved valleys blocked by terminal moraines. The brilliant turquoise color of this river, so stunning on screen, is due to the presence of glacial flour, fine powdered rock ground by glaciers, suspended in the water column.

The world's first bungee jumping bridge crosses the Kawarau River, where the background for the Argonath was filmed. Visitors can bungee off the bridge and touch the "Anduin."
Credit: both: Terri Cook and Lon Abbott

North Mavora Lake stood in for Nen Hithoel in the movies.
Credit: Terri Cook and Lon Abbott

The Argonath and Nen Hithoel

The background for the Argonath — the soaring Pillars of the Kings that the Fellowship passes near the end of their voyage down the Anduin — was also filmed on the South Island, on the Kawarau River close to Queenstown. Although the Argonath's pillars were computer generated, the background is easily recognizable. Devoted Tolkien fans can further immerse themselves in Middle-earth by rafting past the Argonath backdrop on a trip with Extreme Green Rafting, one of the companies that assisted Jackson with filming.

After the Fellowship gazed upon the Argonath, they entered Nen Hithoel, a large lake pooled above the crashing Falls of Rauros where the Fellowship waited for darkness to cross the lake. The scenes along the shore were filmed southwest of Queenstown at North Mavora Lake, the sparkling blue waters of which are nestled among steep, tree-studded slopes. Based on the different metamorphic rock assemblages on either side of the lakes, geologists have concluded that a major fault runs through the center of the North and South Mavora Lakes, creating a depression in which the water has pooled. Some of the hills west of the lakes contain distinctive slivers of ophiolite — ultramafic oceanic crust — that formed during the Early Permian and were added to the edge of Gondwana's overriding continental crust during subduction about 250 million years ago. The presence of similar rocks nearly 500 kilometers to the north helped geologists recognize and measure the displacement that has occurred along the Alpine Fault.

Mordor and Mount Doom

In Middle-earth, Mordor is a desolate and barren land blocked by mountains on three sides and occupied by Sauron for thousands of years during the Second Age. Within this wasteland looms Mount Doom, the volcano where the Dark Lord forged the One Ring, and his imposing fortress of Barad-dûr. The eruptions of Mount Doom are controlled by Sauron, whose power extends into its incandescent fires. Lying dormant while Sauron is away and springing to life as his power grows through the trilogy, Mount Doom is, geologically, a most unusual volcano to say the least.

In the movies, Jackson filmed key scenes from Mordor in the North Island's Tongariro National Park, skillfully using its dark, jagged volcanic rocks to evoke a mood of desolation and despair. The park encompasses the Tongariro volcanic center,

Many scenes in or near Mordor were filmed near the Whakapapa Ski Field on Ruapehu's northwestern slopes on the North Island.
Credit: Terri Cook and Lon Abbott

The other-worldly Mount Ngauruhoe stood in for Mount Doom.

Credit: ©Michel, CC BY-NC-ND 2.0

a complex of andesitic stratovolcanoes built up, eruption by eruption, over the last 275,000 years. Dubbed "the forges of Middle-earth" by the Geological Society of New Zealand in its book "A Continent on the Move," these cones comprise the southern end of the Taupo Volcanic Zone, the long chain of andesitic volcanoes created by the subduction of the Pacific Plate beneath the Australian Plate to the east of the North Island. The most infamous of this chain is Taupo, a supervolcano that produced the largest eruption to occur in the last 70,000 years.

Various parts of the park's spectacular scenery doubled as important Middle-earth locales, most notably Mount Doom, which was modeled after the classically shaped volcanic cone of Mount Ngauruhoe. Only about 2,500 years old, Ngauruhoe most recently erupted in 1975. Variations in the chemistry of lava at Ngauruhoe indicate that its magma forms in small batches within a complex and rapidly changing subterranean plumbing system.

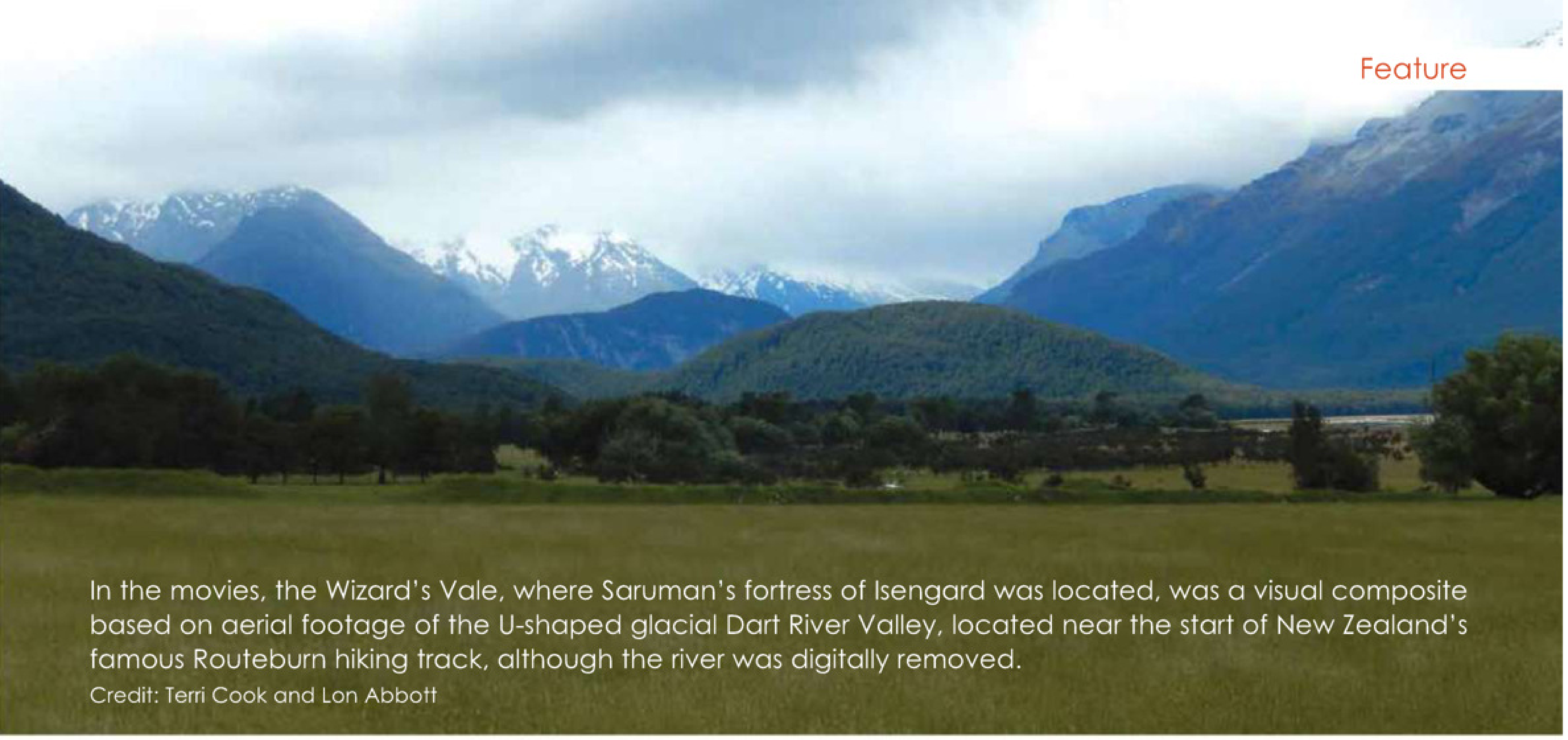
Erupted lava also often contains fragments of partially melted sedimentary and metamorphic rocks torn from the underlying continental crust during the magma's ascent, providing geologists with a window into New Zealand's basement. Because Ngauruhoe's summit is sacred to the local Māori, Jackson wasn't allowed to film it directly, so he used a model and special effects to portray the peak in wide-angle shots.

Part of the same volcanic center, Mount Ruapehu, New Zealand's largest active volcano, is composed of roughly 100 cubic kilometers of material ejected over its 230,000-year history. Ruapehu's most recent eruptions include minor events in 2006 and 2007 and a more spectacular explosion in 1995–1996, which lasted for several months and had an estimated $110 million impact on the North Island's alpine tourism industry. Based on a study of ejected materials on the plains downwind of the volcano, geologists think that eruptions comparable to the 1995–1996 episode have occurred about once a century at Ruapehu for the last 2,000 years.

Many scenes in or near Mordor — including the Battle of the Last Alliance, the capture of Gollum by Frodo and Sam, and the wandering of the lost Hobbits through the labyrinthine Emyn Muil — were filmed near the Whakapapa Ski Field on Ruapehu's northwestern slopes.

The glacial landscapes of the South Island were prominently featured in the movies, including Mount Sunday, a rocky knoll high in the Rangitata River Valley where Rohan's capital of Edoras was filmed.

Credit: above: ©Erik Carlson, CC BY-NC 2.0; right: ©Greg Hewgill, CC BY 2.0



In the movies, the Wizard's Vale, where Saruman's fortress of Isengard was located, was a visual composite based on aerial footage of the U-shaped glacial Dart River Valley, located near the start of New Zealand's famous Routeburn hiking track, although the river was digitally removed.
Credit: Terri Cook and Lon Abbott

Isengard and Edoras

Just as the North Island's geologically young volcanoes have played an important role in creating its modern appearance, glaciers have placed many of the finishing touches on the South Island's beautiful landscape. The ruggedness of the mountains, the deep glacial lakes and the broad, U-shaped valleys were fashioned by these powerful sculptors. This glacial scenery is especially evident at two crucial Middle-earth locations: the Wizard's Vale, where Saruman's fortress of Isengard was located, and Rohan's capital of Edoras.

In the movies, Isengard was a visual composite based on aerial footage of the U-shaped glacial Dart River Valley, located near the start of New Zealand's famous Routeburn hiking track, although the river was digitally removed. Edoras was filmed at an impressive set built atop Mount Sunday, a rocky knoll located in the stunning Rangitata River Valley high above the Canterbury Plains. During the last ice age, which ended in New Zealand 11,500 years ago, this area resisted the erosion that carved out the surrounding land, leaving behind a bare hillock whose sheer sides now overlook braided river channels and windswept tussocks against a backdrop of steep, snow-capped mountains.

Because of the unpredictable weather in this remote alpine valley, Jackson's crews needed almost a year to build the set, which was dominated by Meduseld, the King's golden hall. Although the set was removed after filming, the sounds of the mustering Rohirrim and the raucous feasts in the golden hall still seem to echo across the raw, untouched beauty of this remote and breathtaking setting.

After visiting many of the filming sites and learning more about how these diverse landscapes formed, watching the movies is even more entertaining because I can recall my own Middle-earth adventures hiking near Mount Doom, trying on the One Ring and paddling down the brilliant River Anduin. As actor Elijah Wood, who starred as Frodo, famously said, "New Zealand *is* Middle-earth."

Cook (www.down2earthscience.com) is a science writer based in Boulder, Colo.

Ed Grew in the camp northeast of Lake Ferris on the northern Stornes Peninsula in late spring before much snow had melted.
Credit: Chris J. Carson

Protecting the Mineral Treasures of Antarctica's LARSEMANN HILLS

Edward S. Grew and Christopher J. Carson

It was late November 2003 and not quite summer in Antarctica. As the Squirrel helicopter lifted off after delivering its last load, we set about putting up our two tents and making camp on Stornes Peninsula. The peninsula, which would serve as our home and base for fieldwork for the next two months, is part of the Larsemann Hills, a 40-square-kilometer region of rocky islands and promontories on the eastern shore of Prydz Bay, some 120 kilometers southwest of one of Australia's Antarctic bases, Davis Station. Our only contacts with the outside world were twice-daily radio calls and an occasional helicopter flight to refurbish our larder and take out our samples. No telephone, no Internet.

What brought us to the Larsemann Hills? Boron and phosphorus. These elements are rarely found in more than trace amounts in highly deformed and metamorphosed rocks such as the granulite-facies metamorphic rocks (rocks subjected to temperatures in excess of 700 degrees Celsius) exposed in the Larsemann Hills, yet previous studies had suggested that both elements could be found in abundance here. The objective of our research program, which was supported by the U.S. National Science Foundation and the Australian Antarctic Division, was to determine just how abundant boron and phosphorus were, and to suggest an explanation for why there might be exceptional enrichment.

In the course of carrying out our research, we made many discoveries, which showed just how unusually diverse the minerals in the Larsemann Hills are. One result of our work turned out to be a project that was a decade in the making: In 2014, Stornes Peninsula within the Larsemann Hills was declared an Antarctic Specially Protected Area for its significant mineral diversity. Stornes Peninsula thus became only the fifth location in Antarctica with geologic features deemed sufficiently precious enough to the geologic community to receive this high level of protection.

Chris Carson on sea ice with icebergs in Barry Jones Bay, west of Stornes Peninsula.
Credit: Ed S. Grew

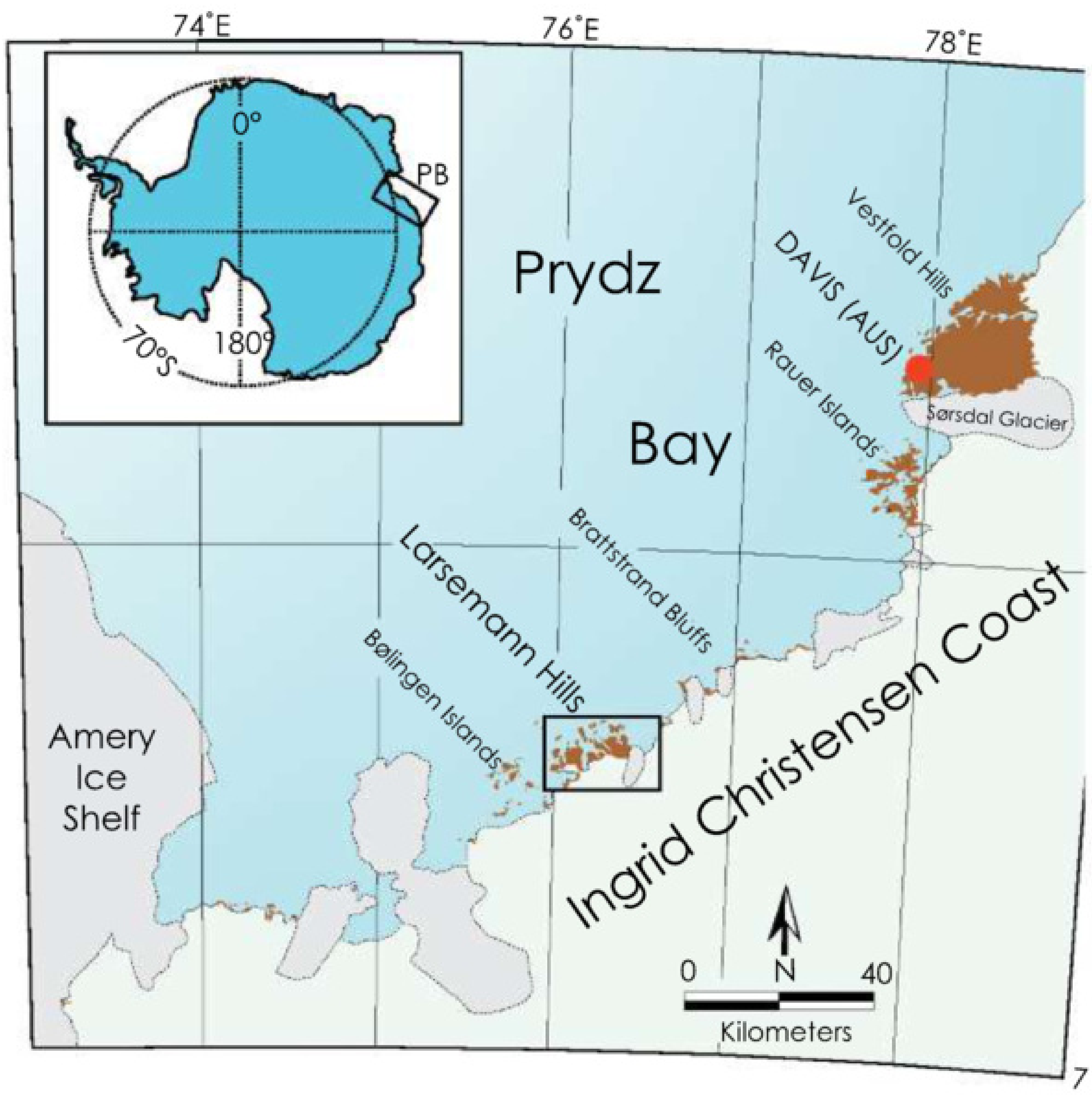
Our Fieldwork

Our camp was set up on a snow field and we had to chop lake ice to melt for our water supply. But once summer set in, the place became downright pleasant. The southeast coast of Prydz Bay has a reputation for fine weather with plenty of sun and relatively mild temperatures, with daytime averages ranging from about 1 degree Celsius in late November to 4 to 5 degrees Celsius in December and January. And we were not disappointed. Once the wind died down in the morning, working on outcrops was a delight. At 69 degrees South latitude, the "white nights" in midsummer can be lovely, making for serene scenes in low light. We celebrated Christmas with dinner al fresco.

The price for these pleasant conditions was wading at least knee-deep through snow softened by the intense sunlight, and unpleasant surprises such as finding our camp threatened by rising lake waters. (Mercifully, the lake receded before it engulfed us.) We did not have mechanized transport with which to reach distant exposures and haul our samples; all our traverses were on foot. Some outcrops were conveniently at our doorstep; others entailed trudging up to 10 kilometers over sea ice, which was often covered in soft snow, or across hummocky terrain of rock and snow. The Larsemann Hills top out at the 162-meter-tall Blundell Peak, but this modest height belies a rugged landscape with many ups and downs to negotiate.

By the time we were picked up by helicopter in late January for our return home, the snow had largely disappeared from the area around our camp, and the nearby lakes had melted enough so we could simply scoop up lake water to meet our needs.

Once we returned home, our work involved years of analyzing the mineral samples we had collected.



Map of Prydz Bay showing the location of the Larsemann Hills. The inset shows the location of Prydz Bay (PB) within the Antarctic continent.
Credit: Chris J. Carson

The Mineral Treasures

The Larsemann Hills were first noted in 1935 by members of a Norwegian whaling expedition. A few expeditions studied the area's geology between the 1950s and the 1970s; one of us (Ed Grew) visited an offshore island with the Soviet Antarctic Expedition in 1973. However, detailed geological investigations only commenced in the late 1980s.

One of the first "finds" in the hills consisted of large, abundant prisms of a black mineral reported to be "tourmaline," a relatively common borosilicate mineral familiar to amateur and professional mineralogists alike. Several years later, Chinese and Australian geologists (including Chris Carson) showed that the large prisms were actually prismatine — another silicate mineral containing boron as an essential constituent, but far

THE AMAZING MINERALS OF THE LARSEMANN HILLS

Four minerals were discovered on Stornes Peninsula in the Larsemann Hills of East Antarctica based on fieldwork there from 2003 to 2004. In part because of these minerals and other rare boron and phosphate minerals found in this pristine region, Stornes Peninsula is now protected as an Antarctic Specially Protected Area — the highest level of environmental protection in Antarctica. Below are some details about these special minerals.

Boron Minerals

PRISMATINE: a borosilicate mineral composed largely of magnesium, iron and aluminum, that together with its boron-poor analog kornerupine, has been found in 70 to 80 localities worldwide, mostly in ancient rocks crystallized at depth like those found in the Larsemann Hills.

GRANDIDIERITE: a green-blue borosilicate also containing magnesium, iron and aluminum found in about 40 localities worldwide in a variety of rocks. Forms lath-like prisms.

TOURMALINE: widespread in a variety of sedimentary, metamorphic and igneous rocks worldwide. Worm-like intergrowths of black tourmaline with quartz are characteristic of the Larsemann Hills, where tourmaline also occurs in fine-grained, sugary textured aggregates or in layers of "tourmalinite," a massive black rock composed almost exclusively of tourmaline and quartz.

Worm-like intergrowth of tourmaline (black) and quartz (gray) can be seen in this pegmatite sample from the northern Stornes Peninsula. The yellowish-pink mineral is microcline.

Credit: Ed S. Grew

Spectacular randomly oriented prismatine prisms on a foliation plane can be seen in this outcrop east of Prismatine Peak on the Stornes Peninsula.

Credit: Ed S. Grew

BORALSILITE: the first new mineral found in the Larsemann Hills. This borosilicate was first described in 1998 in a specimen collected near Prismatine Peak some 10 years earlier by Australian photographer Douglas Thost, who has done extensive geological and glaciological fieldwork in Antarctica. During the 2003–2004 season, we found boralsilite at nine localities on Stornes Peninsula. There are only two other localities worldwide where this mineral has been found to date: Almgjotheii, Rogaland, Norway, and Horní Bory, Bory Granulite Massif, Czech Republic.

DUMORTIERITE: a widespread borosilicate mineral of aluminum that contains minor amounts of arsenic and other metals. In the Larsemann Hills it is found in bright-blue fibrous mats and gray centimeter-sized prisms.

WERDINGITE: a borosilicate of magnesium, aluminum and iron related to boralsilite in its crystal structure known only from a single thin section in which it is present as a microscopic constituent.

more limited in occurrence. Correcting the mineral identification resulted in the renaming of Tourmaline Peak to Prismatine Peak, the official name for the prominent hill on central Stornes Peninsula where prismatine spectacularly occurs.

Prismatine was only the first unusual boron mineral to be found in abundance. Numerous other boron and phosphorus minerals were also found over the next few decades. Our fieldwork in 2003–2004 showed that prismatine and other minerals such as grandidierite and tourmaline were not limited to isolated outcrops, but instead were enriched in several stratigraphic units. The rocks exposed in the Larsemann Hills had sedimentary precursors unusually enriched in boron; this boron had not been driven off and lost during high-temperature metamorphism as is usually the case in such metamorphic complexes.

The yellow-orange mineral wagnerite in a matrix of biotite, prismatine, cordierite and oxides. This sample of schistose granulite was taken from the base of Gneiss Peak on the northern Stornes Peninsula.
Credit: Ed S. Grew

Phosphate Minerals

WAGNERITE: a new polytype of magnesium fluorphosphate that forms bright orange masses up to 3 centimeters across. (Polytypes of a mineral differ from one another in crystal structure, but not enough to be considered distinct mineral species.)

STORNESITE-(Y): discovered in the Larsemann Hills and only found there. It is a sodium-calcium-magnesium-rich phosphate, named for the Stornes Peninsula and for the element yttrium, the most abundant of the rare-earth elements (hence the 'Y' designation to distinguish it from a stornesite containing another rare-earth element). Its closest relative is the yttrium-free meteoritic mineral chladniite.

TASSIEITE: discovered in the Larsemann Hills and only found there. It is named for Tassie Tarn on Stornes Peninsula, which has an outline resembling that of Tasmania. The mineral is a blue-green sodium-calcium-iron-magnesium phosphate containing water molecules in its crystal structure.

CHOPINITE: discovered in the Larsemann Hills and named for French mineralogist Christian Chopin of the École Normale Supérieure, Paris, for his major contributions to phosphate mineralogy. It is the magnesium-dominant analog of the iron-phosphate mineral sarcopside. Four grains less than 1 millimeter across in a single thin section from Brattnevet, which is located between Stornes and Broknes peninsulas, constitute all the known terrestrial examples of chopinite; the only other occurrence is meteoritic.

MÉLONJOSEPHITE: a microscopic calcium-iron phosphate enclosed in apatite known from just four localities in the world other than the Larsemann Hills.

ISOKITE: a fluorphosphate of calcium and magnesium found in microscopic veinlets cutting through wagnerite; it is known from no more than 10 localities in the world.

ESG and CJC

Blue grandidierite prisms in gneiss with the aluminosilicate sillimanite (white prisms) and tourmaline (dark) can be seen in this sample from the Wilcock Bay area on the southern Stornes Peninsula.
Credit: Ed S. Grew

Grew (left) and Carson enjoy Christmas dinner at camp.
Credit: Chris J. Carson

And the unusual boron mineralogy was not limited to the vicinity's metasedimentary rocks. Granitic pegmatites formed by partial melting of the metasediments also featured spectacular development of borosilicates, many of which have only been found in Antarctica and perhaps one or two other locations around the world.

Our fieldwork also revealed a surprising abundance of phosphate minerals, including three new species, two of which have never been seen outside of the Stornes Peninsula. Between those and the new boron mineral, we found four new minerals for which Stornes Peninsula is the type locality (see sidebar). And the new boron mineral is recognizable in hand specimens — exceedingly rare for recently discovered minerals. Most modern mineral discoveries are based on microscopic occurrences and observations.

Providing a Geologic History

The unusual minerals in this small area, in addition to their rarity and visual appeal, have provided us with glimpses into the geological evolution of the Larsemann Hills area; the unique mineral diversity resulted from distinctive aspects in its geologic history. On the basis of whole-rock geochemical and mineral boron isotope data, we attribute the enrichment of the sedimentary precursors in boron and phosphorus to hydrothermal alteration prior to metamorphism. The precursor rocks included sandy and clayey sediments mixed with volcanic ash (tuff) and boron-rich salts resulting from evaporation, in a nonmarine basin.

Based on our investigations, it appears these rocks were deposited in a rift basin, in which circulating hydrothermal fluids leached boron from the evaporitic deposits and

Carson makes his way across "Eliza Kate" Island northeast of Stornes Peninsula.
Credit: Ed S. Grew

The view north over camp on New Year's Eve. For several days, the team's approach to camp was blocked by rising lake water that necessitated a detour. The icebergs in the distance remained at least until departure and probably through the entire summer.
Credit: Ed S. Grew

transported it to the interbedded sandy and clayey sediments. These later recrystallized to form the gneisses and granulites that compose the metasedimentary complex exposed in the Larsemann Hills. We think that the rifted basin was 400 to 500 kilometers landward of a 1-billion-year-old continental arc, which was active along the leading edge of a craton comprising the most ancient rocks now found in southern India and a part of Antarctica. Collision with small terranes 990 million to 900 million years ago resulted in burial and metamorphism of these sediments. Then, about 530 million years ago, this craton (plus the accreted terranes) collided with another craton comprising parts of Australia and Antarctica to form the supercontinent Gondwana. Along the collision zone the sediments were again heated and deformed under conditions that allowed the boron to remain in the rocks as they recrystallized and melted, giving us the distinctive borosilicate minerals we find in the Larsemann Hills, but rarely elsewhere.

Protecting the Stornes Peninsula Treasures

As the new and rare minerals came to light during our study of samples in the first two or three years after returning from the field in 2004, we raised the possibility of protecting this region with the Australian Antarctic Division, which acknowledged the importance of the area. Australia took the lead, working with China and the Russian Federation as all three have bases on the next peninsula to the east of Stornes, called the Broknes Peninsula, also in the Larsemann Hills. They prepared a management plan to designate the Larsemann Hills an Antarctic Specially Managed Area and presented it before the Committee for Environmental Protection under the Antarctic Treaty System. This designation establishes a formal framework to ensure close collaboration and cooperation in science, operations and environmental protection. In 2007, the management plan for the Larsemann Hills was endorsed by the 10th meeting of the Antarctic Treaty's Committee for Environmental Protection, in conjunction with the 30th Antarctic Treaty Consultative Meeting.

The team was picked up by a helicopter for the flight back to Australia's Davis Station after striking camp and concluding fieldwork.
Credit: Ed S. Grew

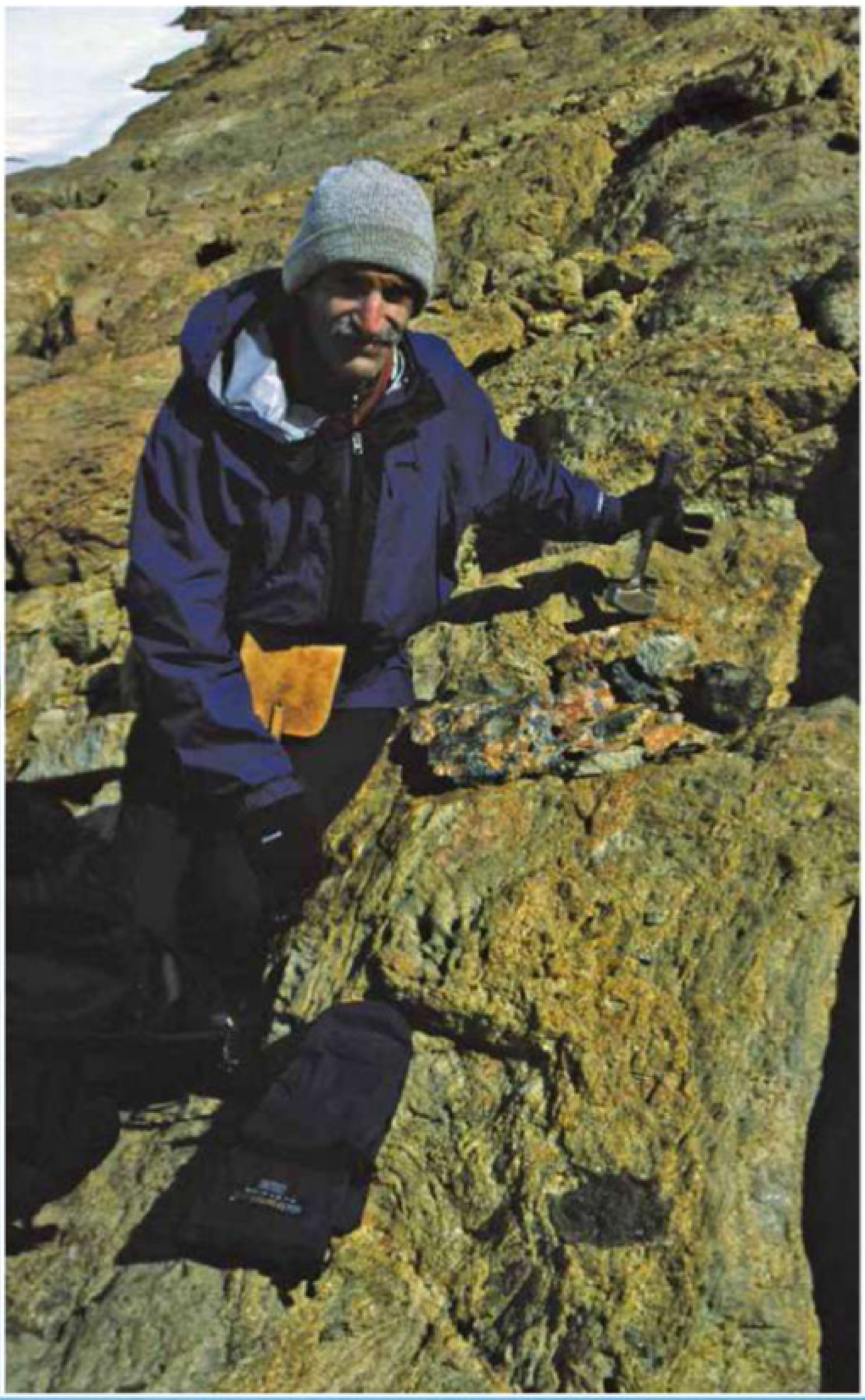
The next step was a proposal for the Stornes Peninsula to be made an Antarctic Specially Protected Area (ASPA-174) — the highest level of environmental protection under the Antarctic Treaty's Protocol on Environmental Protection. This level of protection is used to safeguard outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those, or ongoing or planned scientific research. Again, Australia took the lead in preparing and presenting the proposal to the treaty parties; the motion was jointly sponsored by other nations with geological research programs in the Larsemann Hills, including China, India and the Russian Federation. The proposal was adopted at the 37th Antarctic Treaty Consultative Meeting in 2014. Through all of this we contributed to the geological case for protection in the management plans.

The main aim of the protection designation, as specified in the Management Plan for ASPA-174, is to avoid degradation of the protected area by preventing human disturbance and inappropriate collection of rocks and minerals. Scientific research is allowed if justified by compelling reasons, such as the impossibility of carrying out similar research elsewhere; however, a permit is required. Samples can be collected in moderation and if properly documented; and in permit reports, scientists must provide the GPS locations of collection sites, the amounts of material collected at each, and information about the repository where samples are deposited.

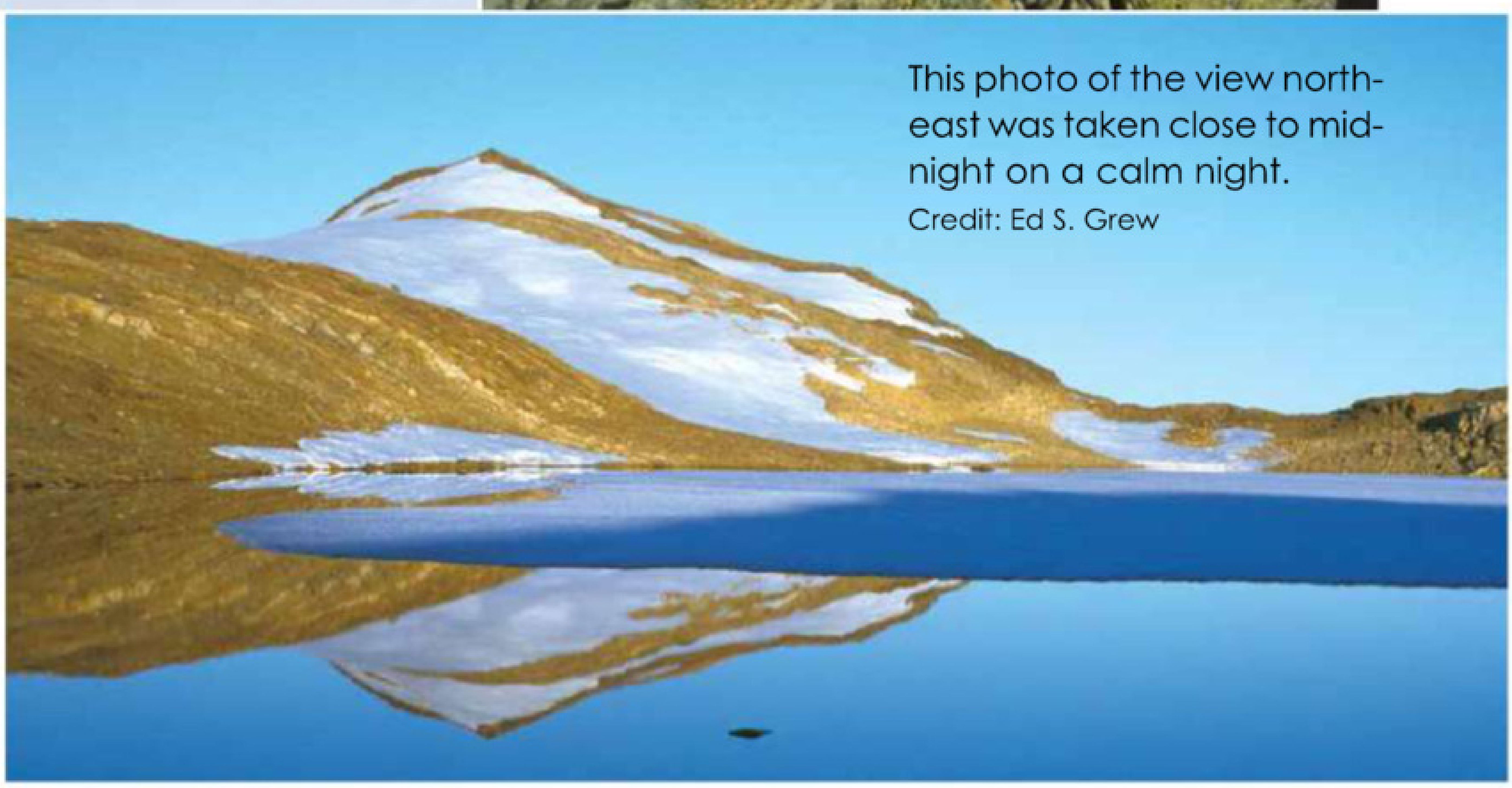
There were several factors involved in selecting the Larsemann Hills for protection. The primary factor was the significance of the region for the mineralogical sciences. Four new minerals were found here, and Stornes is noteworthy for the unique abundance and spectacular development of other minerals whose beauty can be appreciated in outcrop and hand specimens with the naked eye. These minerals are rare globally, and, more often than not, they occur only as microscopic crystals at other localities.

There were also nonmineralogical factors that contributed to the case for Stornes Peninsula being declared an ASPA. One was the presence of 4-million-year-old sediments containing abundant and well-preserved foraminifera, diatoms and mollusks that provide information on Antarctica's paleoenvironment at a time when ice volume was reduced relative to today. It is one of only two such sites of this age in East

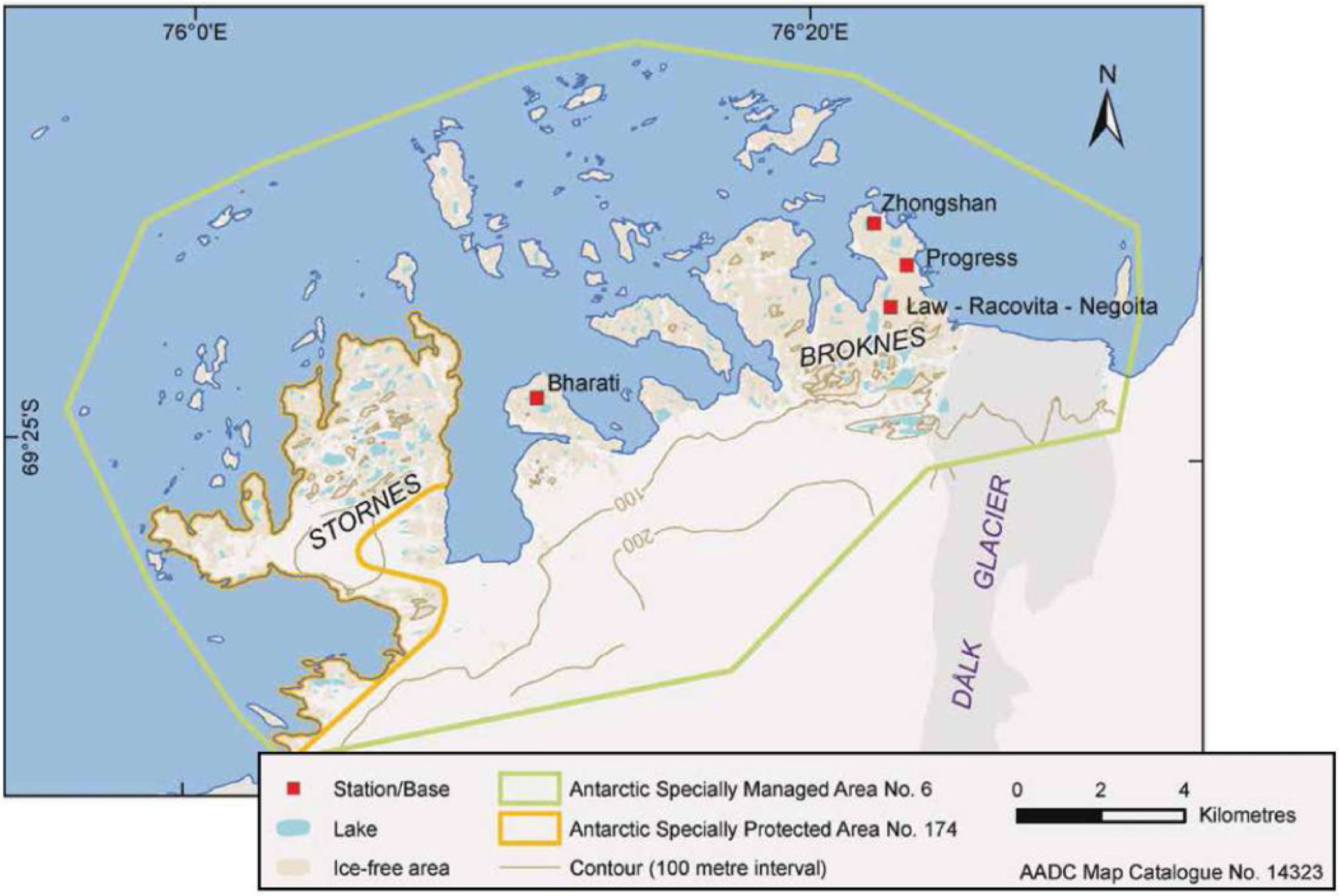
Grew with samples of granitic pegmatite containing the borosilicate minerals tourmaline, dumortierite and boralsilite on the northern Stornes Peninsula.
Credit: Chris J. Carson



Carson stands in a steep depression partially filled with drifted snow. The view north toward Johnston Firth in western Stornes Peninsula illustrates the terrain's ruggedness and intrinsic visual beauty.
Credit: Ed S. Grew



This photo of the view northeast was taken close to midnight on a calm night.
Credit: Ed S. Grew



Map of the Larsemann Hills, showing outlines of the Antarctic Specially Managed Area (green line), which encompasses all the rock exposures, and of the Antarctic Specially Protected Area (orange line) enclosing most of Stornes Peninsula.

Credit: courtesy of the Australian Antarctic Division

Antarctica. The sediments are thin and disintegrate easily, and thus require protection from human disturbance.

The ice sheet on Stornes, which is small and has almost no connection with the main Antarctic ice sheet, could respond rapidly to climate change. Studies of this site are important. Stornes has been infrequently visited and is minimally impacted by human activities; it thus also serves as a reference site for comparison with other peninsulas in the Larsemann Hills — notably the Broknes Peninsula, which has been significantly altered as a result of the research stations operating there.

Another consideration is the area's vulnerability. For all its remoteness, the Larsemann Hills is rather populated by Antarctic standards. Although abundant icebergs and sea ice remain close to land late into the austral summer, neither is a deterrent to icebreakers that service the stations during the brief Antarctic summer. Consequently, the Larsemanns have been "occupied" since 1986, with five nations having set up field huts or established research bases at some point between then and now.

A final consideration is aesthetics. Unlike Broknes Peninsula, Stornes Peninsula has not been subject to year-round occupation. The closest winter-over station is an Indian station on nearby Grovnes Peninsula. The beautiful scenery and unique geology of Stornes Peninsula should be kept pristine. And now, thanks to the efforts of many scientists and policymakers from several countries, it may remain so.

Grew is a research professor in the School of Earth and Climate Sciences at the University of Maine in Orono. He has worked with Soviet, Australian, Japanese and U.S. expeditions to Antarctica, including a winter-over at the former Soviet station, Molodezhnaya. His specialty is the mineralogy of boron and beryllium species. Carson is a senior Antarctic geoscientist with Geoscience Australia in Canberra. He has worked in high-grade metamorphic terrains in Antarctica, the Canadian Arctic, Alaska, New Caledonia and northern Australia, specializing in metamorphic petrology and structural geology. The authors thank Davis Station leader Bob Jones and other members of the 2003–2004 Australian National Antarctic Research Expedition for logistics support during the summer field season in the Larsemann Hills.

Travels in Geology

Navigating the Rocks, Reefs and Waters of BERMUDA

Sam Lemonick

The Bermuda Triangle is not an actual scientific phenomenon. But if a family were looking for a place to disappear to for a week or so, Bermuda is a great choice. Picturesque beaches, beautiful weather and a pleasant mix of Caribbean and British cultures make it a popular vacation destination. It's also a place where geology and history are on display, making both relaxation and exploration easy.

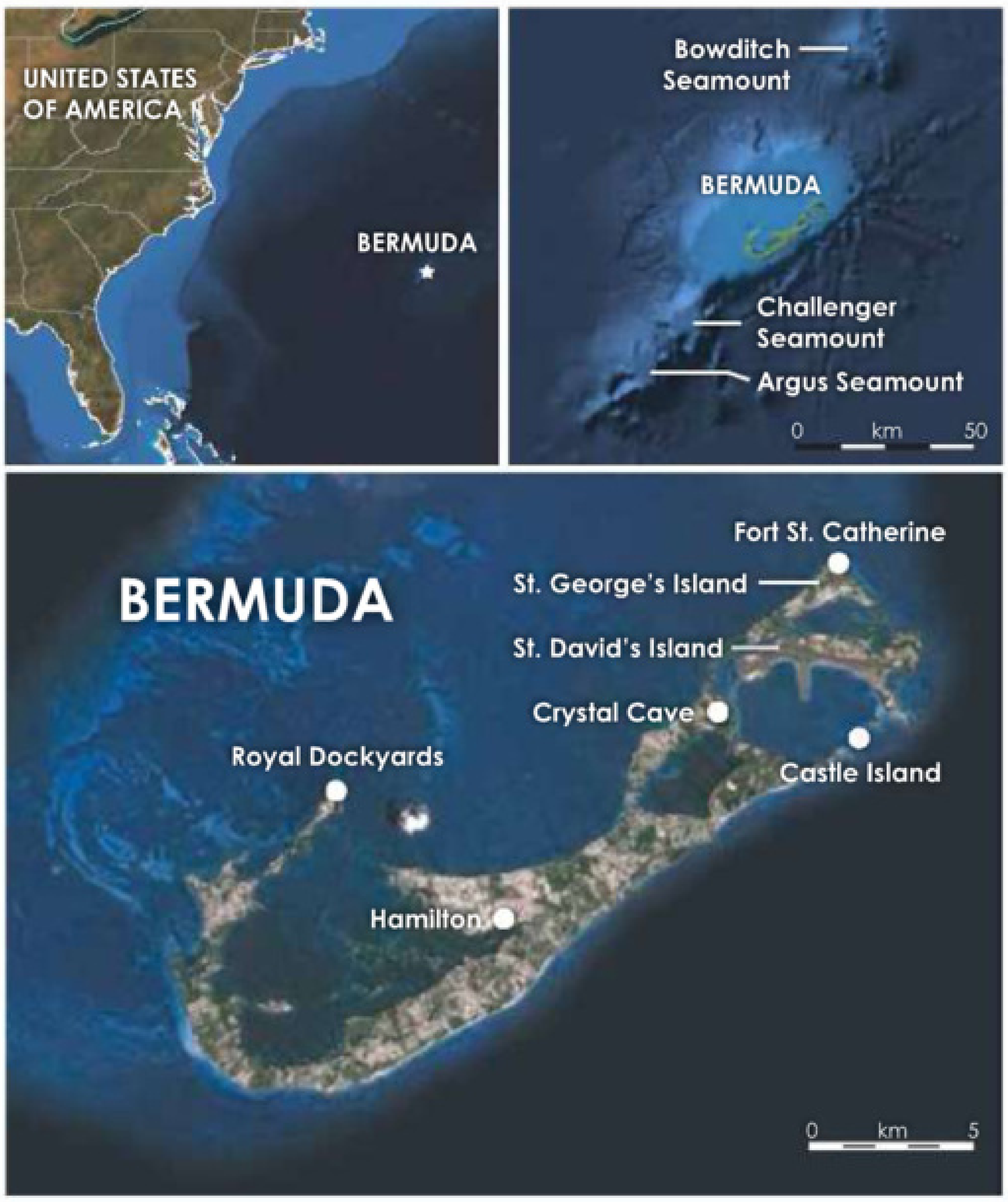
Much of Bermuda's coastline is rocky but the south shore hosts beautiful pink and white sand beaches.
Credit: Kelly Speare

VOLCANIC BEGINNINGS

Bermuda, a former British colony, inhabits a compact group of islands on the southeastern edge of a large reef in the Atlantic Ocean, about 1,030 kilometers east of Cape Hatteras, N.C. Bermuda itself is a group of islands sitting on one of four seamounts — Bermuda, Challenger, Bowditch and Argus — in a 100-kilometer-long chain running southwest to northeast. The seamounts rest atop the crest of a similarly trending swell, called the Bermuda Rise, that measures 1,500 kilometers long and 500 to 1,000 kilometers wide. The origins of the seamounts and the rise are one focus of the ongoing geological debate over the existence of mantle plumes.

The mid-plate seamounts formed between 45 million and 35 million years ago. Superficially, they resemble the Hawaiian chain and have previously been attributed to hot spot volcanism, but other geologists think they formed during a period of heightened volcanic activity worldwide, while tectonic plates were jostling against each other as the ancient supercontinent Gondwana was finishing its breakup.

Today, the rocks seen above water are almost exclusively limestone, sculpted by wind and waves.
Credit: Kelly Speare



Bermuda comprises a compact group of islands on the southeastern edge of a large reef in the Atlantic Ocean, about 1,000 kilometers east of Cape Hatteras, N.C. The islands of Bermuda sit on one of four seamounts — Bermuda, Challenger, Bowditch and Argus — in a 100-kilometer-long chain.
Credit: Kathleen Cantner, AGI

An earlier theory suggested that Bermuda and the other seamounts formed as part of a massive eruption along the Mid-Atlantic Ridge. But geologists have invalidated this idea based on boreholes drilled into the seafloor that show that the seamounts themselves are much younger than the crust beneath them, which formed at the Mid-Atlantic Ridge about 100 million years ago.

The Bermuda volcano may once have stood as high as 1,000 meters above sea level, but it has long since eroded down to a large plateau; only 7 percent of the plateau is above the ocean surface today. Around the edges of the volcano, coral reefs have formed. Over millions of years, the shells and bones of other sea creatures and ancient reefs settled on the seafloor and were compacted into limestone. The plateau extends northwest from the island about 10 kilometers in a large reef, but off the island's southeastern coast there are only a few kilometers of shallow water before the shelf drops precipitously. During glacial cycles, sea levels rose and fell, variously exposing and covering Bermuda's igneous and sedimentary rocks. Today, the above-water island rocks are almost exclusively limestone, sculpted by wind and waves. Around them, cold-water reefs still grow, forming some of the northernmost reefs in the world.

Bermuda is home to a vast system of caves, including Crystal Cave, which boasts impressive stalactites and stalagmites. Caves on the islands are both above and below water.

Credit: left: ©Shutterstock.com/Russ Hamilton; bottom left: Grace Ballou; bottom right: Kelly Speare

BENEATH THE SURFACE

Because limestone is a fairly soft rock and susceptible to dissolution, Bermuda is home to a vast system of caves, both above and below water. Scientists think these caves mostly formed when sea levels were lower. Rain — the only source of freshwater on Bermuda — has also carved sinkholes and more than 150 caves across the island.

The most famous of these is Crystal Cave — a developed tourist site in Hamilton Parish toward the northeastern end of the island and just a few minutes from the airport — where visitors can take a guided tour on a series of floating walkways. Although the colored lighting in the cave makes it feel a bit like a nightclub, it is gorgeous nonetheless, with stalactites and stalagmites of all shapes and sizes; the artificial light does make it much easier to see the features than would a headlamp.

Crystal Cave abuts Blue Hole Park, which has its own caves for those looking for a less-commercial experience. They don't rival Crystal Cave, but water shoes, a bathing suit and a flashlight are all you need to check them out. Two interconnected caves, separated by a thin curtain of limestone columns, are accessible. Each cave is a few hundred square meters and flooded with less than a meter of water. The bottom is mostly sandy, but there are some treacherous rocky spots. Hundreds of stalactites hang from the caves' roofs, which are high enough in most places to walk under, but low enough that you should keep an eye out for them. With a keen eye, you might even be lucky enough to spot a cave lobster.

Geologists suspect sea caves are also hidden in the depths around the island and reef. The evidence for the existence of undiscovered caves comes from crustaceans and other cave dwellers, some of the island's only native animals. Geologic records show that all known Bermudian caves were above sea level during the last glacial maximum about 18,000 years ago. But some of these species are thought to have existed locally for millions of years, suggesting these animals retreated to deeper caves until sea levels rose again. These former habitats may still exist.

Small, whitewashed houses with peculiar roofs shaped like angular beehives are designed to channel rainwater into cisterns, from which Bermudians get almost all of their freshwater.

Credit: left: ©Shutterstock.com/Peter Rooney; above: Kelly Speare

A STRATEGIC SPOT

Aboveground, Bermuda's landscape features low, rolling hills dotted with small trees. The shoreline is mostly rocky with tide pools, although gorgeous white sand beaches occasionally break up the rugged terrain, especially on the southern coasts. Small, whitewashed houses with peculiar roofs shaped like angular beehives or Aztec pyramids are the norm. The roofs are designed to channel rainwater into cisterns, from which Bermudians get almost all of their freshwater (the remaining water comes from wells that tap the island's few freshwater lenses). Because of the water resource constraints, Bermudians have long since adapted, even teaching their children about conservation with a simple rhyme: "In the land of sun and fun, we never flush for number one." (In other words, do not flush the toilet when you urinate.)

Nearly as ubiquitous as the distinctive roofs — and Bermuda shorts — are the forts that line the island's shores. It was only in the early 20th century that Bermuda transformed into the popular tourist destination it is now. The island became a British naval outpost during the American Revolution, and the British government continued to fortify it throughout the 19th century. Narrow navigable passages through Bermuda's reefs made it almost impossible for enemies to reach the island quickly; the difficult navigation also made enemy ships easy targets for cannon fire from the shore.

Because of Bermuda's lack of timber and its strategic importance, it was one of the first places in the Western Hemisphere to have stone forts. Castle Island is the oldest standing British fort on Bermuda, and at just over 400 years old, is the oldest stone fort in the hemisphere. It and the other forts around St. George — the original settlement on Bermuda, dating to 1612 — make up the Historic Town of St. George and Related Fortifications World Heritage Site. Castle Island is now a conservation refuge for the endangered Bermuda skink and the Cahow bird, so it isn't open to the public. Other parts of the World Heritage Site are open, however, and other forts on the island, like Fort St. Catherine on Bermuda's northeastern tip, can be toured after paying an entrance fee. Many other forts are free, and visitors can wander through them looking at explanatory placards and nonfunctioning cannons.

Bermuda's landscape features low, rolling hills dotted with small trees.

Credit: Christopher M. Keane

Because of Bermuda's lack of timber and its strategic importance, it was one of the first places in the Western Hemisphere to have stone forts, several of which can still be toured today, such as Fort St. Catherine.

Credit: Christopher M. Keane

Much of the largest fort complex, the Royal Naval Dockyard, still stands and now houses the National Museum, which offers a variety of exhibits detailing Bermuda's history, of which the buildings themselves, which once housed soldiers, gunpowder, prisoners and more, are a part.

Credit: Christopher M. Keane

Bermuda's isolation and long military history have also resulted in a unique record of military and artillery development. Whereas obsolete cannons and artillery pieces in other parts of the world were usually melted down and the metal recycled, Bermudians lacked the means to do so, and shipping the huge guns back to England was impractical. Instead, many were kept or simply dumped over a fort's walls into the sea below. Some have been recovered and restored and are now on display at forts around Bermuda.

Much of the largest fort complex, the Royal Naval Dockyard, still stands and now houses the National Museum, which offers a variety of exhibits detailing Bermuda's history, of which the buildings themselves, which once housed soldiers, gunpowder, prisoners and more, are part.

Of particular interest in the National Museum is an exhibit about shipwrecks. Bermuda's British colony was founded by survivors of one fateful wreck, the Sea Venture, which was part of a group of ships sailing to the Jamestown colony in Virginia. And countless other wrecks have occurred on Bermuda's reefs, which lie precariously in the middle of otherwise open ocean, along well-trafficked shipping routes, near the path of the powerful Gulf Stream.

Visitors to the museums can view artifacts from shipwrecks, including gold coins, jewelry, weapons and navigation tools. They can also learn about how researchers (and looters) have explored the reefs over the years, using free diving, diving bells — a chamber open on the bottom that can be lowered to the seafloor with free divers inside — and scuba and other modern equipment.

Hundreds of ships have wrecked just offshore of Bermuda; many are still viewable from shore.
Credit: Kelly Speare

EXPLORING UNDERWATER

Some of the 300 or so estimated wrecks around Bermuda can be visited in person too. Older wrecks are best seen on the western end of Bermuda, whereas more modern ships, including an ocean liner, racing yachts, freighters and warships, can be found to the east.

The paddle-wheel steamer Montana sits in just a few meters of water, where it wrecked trying to refuel in Bermuda on the way to run a Union Army blockade during the Civil War. With a snorkel and fins it's easy to see the intact bow and stern, including the paddle wheel. Other wrecks, like the enormous Cristóbal Colón or the 19th-century iron-hulled sailing ship North Carolina, require scuba equipment. Exploring any of the wrecks, whether by snorkel or scuba, requires booking an excursion through one of Bermuda's many dive shops.

Bermuda's proximity to the United States, its familiar culture and its leisure attractions have long made it a popular choice for stateside travelers. The beaches are concentrated along the southern coast and are a mix of public and private. Some feature Bermuda's famous pink sand, a result of single-celled, red-shelled foraminifera that live on the reefs. It also has the highest concentration of golf courses in the world, with nine located across the islands' 53 square kilometers. These courses, six of which are private but still accessible to visitors, attract some of the world's best golfers. Visitors can also explore the island by bike or on horseback. But off the links and away from the beaches, the country offers a diversity of fascinating and accessible geological and archaeological attractions sure to thrill any curious geotourist.

Other shipwrecks are easily explorable with simple diving equipment.
Credit: ©David Lawrence, CC BY-NC-SA 2.0

Lemonick is a freelance writer in Washington, D.C.

Bermuda has the highest concentration of golf courses in the world; six of the nine courses, including Turtle Hill Golf Club at the Fairmont, are private.

Credit: ©David Kirsch, CC BY-NC-ND 2.0

GETTING THERE & GETTING AROUND

Several major airlines serve Bermuda's L.F. Wade International Airport, located on St. David's Island about 30 minutes from Bermuda's capital and largest city, Hamilton. Dozens of bus routes can take passengers to almost any place on the island, but getting to and from the airport — or anywhere with large suitcases — on the bus is frowned upon. Instead, take a taxi. Rental cars are not available to visitors. The alternative is scooters, but nerves of steel and good health insurance are a must for navigating the narrow, windy, high-speed roads. And although the island is small — less than two-thirds the size of Manhattan — and many places are within walking distance, few roads outside Hamilton have sidewalks or even shoulders. A handful of ferry routes can also help you reach some destinations.

Some visitors choose to rent scooters to get around Bermuda, but taxis are a more popular option.

Credit: ©ElbowBeachCycles (www.elbowbeachcycles.com), CC BY-NC-ND 2.0

Hamilton has several large hotels, and other hotels and resorts are scattered around Bermuda, including a number of smaller guesthouses and bed-and-breakfasts. High-end resorts generally have their own bars and restaurants, and many have golf courses, tennis courts and beaches for guests to use. Most hotels also rent boats, snorkel gear and other equipment. Bermuda uses U.S. dollars interchangeably with its own currency, the Bermudian Dollar.

Without a native population, Bermuda doesn't exactly have a local cuisine, but British and Portuguese inspirations are most common, and seafood is ubiquitous. Hamilton boasts the bulk of the island's restaurants, particularly for fine dining, but St. George and other small towns have good fare as well. Bermudians are often more formal than Americans might be used to, but are generally friendly and helpful. A warm "Good morning" or "Good afternoon" goes a long way.

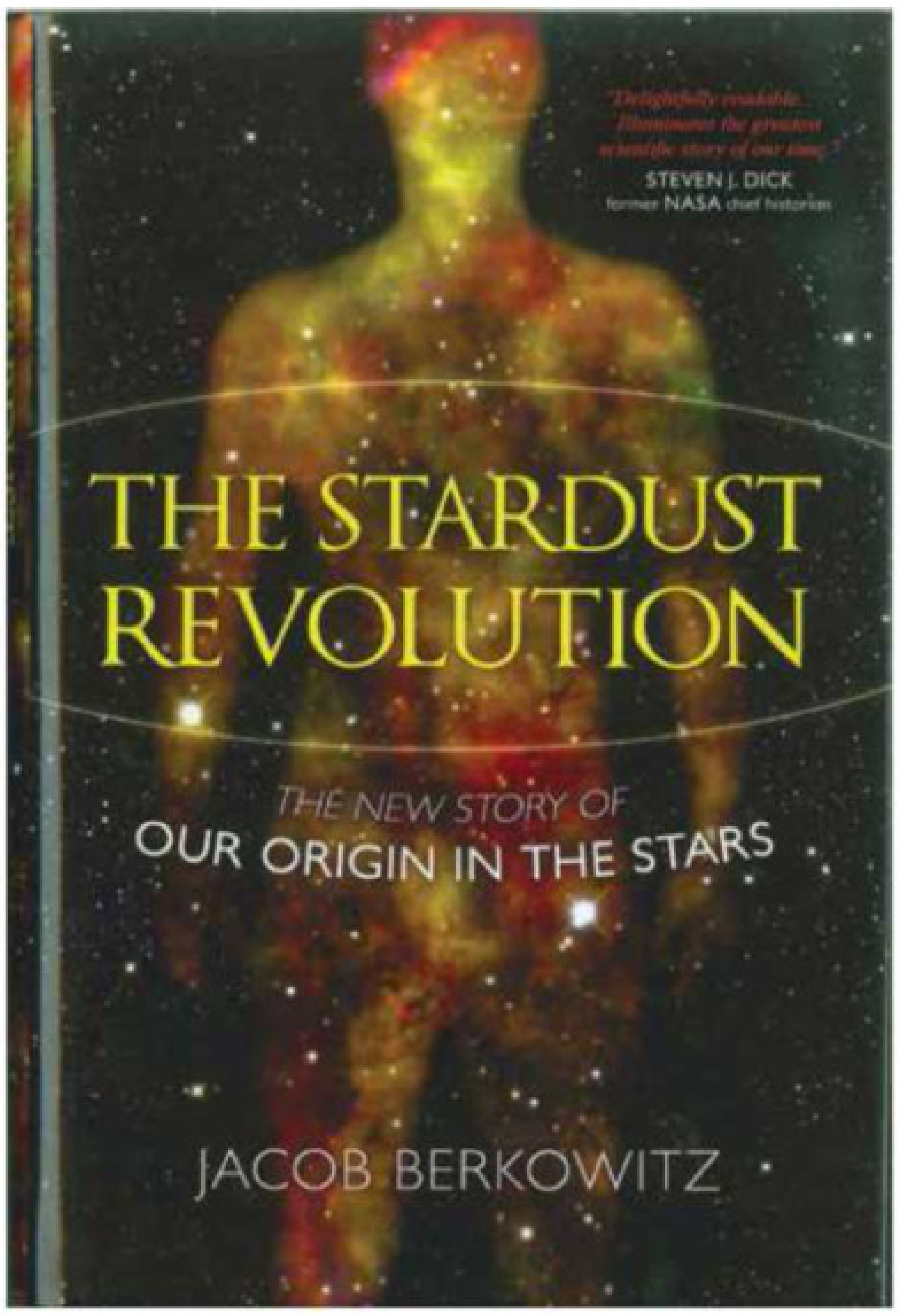
SL

Books: A Brief History of Our Cosmic Origins

Jacob Haqq-Misra

In the 1980 television show “Cosmos,” astronomer Carl Sagan famously noted: “The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff.” This scientifically and philosophically profound concept — that we are starstuff through and through — has been known for less than 50 years, and the history of its discovery was fraught with naysayers.

Today, the notions that all the elements of the universe were forged in the fiery furnaces of stars, and that organic molecules exist in space, are considered textbook knowledge. How that came to be is the subject of Jacob Berkowitz’s book, “The Stardust Revolution: The New Story of Our Origin in the Stars.”



“The Stardust Revolution: The New Story of Our Origin in the Stars,” by Jacob Berkowitz, Prometheus Books, 2012, 9781616145491.

Berkowitz takes the reader on a journey that begins with the first stars that formed after the Big Bang. These first stars contained only hydrogen and helium, but the process of nuclear fusion gradually generated the elements in the periodic table numbering up to iron — and the dramatic core collapses of dying massive stars fused iron into the rest of the naturally occurring elements (ranging up to uranium) as these stars exploded as supernovae. This process, known as nucleosynthesis, is the primary focus of Berkowitz’s book, as it provides a theme linking astronomy, chemistry and biology.

Berkowitz highlights the interdisciplinary collaborations needed to understand nucleosynthesis and how these forces led to the establishment of astrobiology and astrochemistry. Astronomer “planet hunters” also contribute to the extension of biology into space by looking for potentially habitable planets orbiting other stars — a possibility once thought confined to the realm of science fiction. Berkowitz is keen to identify times in the recent past when now well-established ideas were thought to be impossible — a common theme throughout the book.

Berkowitz’s history is colored with characters who bring the process of science to life. Interwoven with descriptions of spectroscopy, nucleosynthesis and radio astronomy are individual perspectives and nearly forgotten anecdotes that exemplify the humanity of the scientists who often overcame tremendous personal struggles in order to pursue their passion for scientific knowledge.

One example comes from the difficulties faced by astronomer Margaret Burbidge (who later became the first female president of the American Astronomical Society) in gaining access to the telescopes on Mount Wilson near Pasadena, Calif. In 1955, observatory policy stated that “two things weren’t allowed: whiskey (in fact, all alcohol) and women,” Berkowitz writes. In order to collect crucial observations that would help to establish stars as the birthplace of elements, Burbidge first had to agree to reside in separate quarters and avoid men outside her team — all while hiding the fact that she was pregnant.

Although the narrative draws out at times, the combination of personal history and scientific exposition — one of the book’s strengths — successfully illustrates how incremental steps contribute to the “big picture” in science.

Overall, the book provides a unique historical approach to the emergence of astrobiology that should be digestible for a wide range of audiences. The book is ideal for science enthusiasts already familiar with some of the major concepts in astronomy, and scientists will appreciate the careful interviews and personal stories.

The book concludes with a philosophical discussion about the possibility of life on other worlds. If we truly are made of stardust, along with our planet and everything else, and if organic molecules really are plentiful in space, then it is possible that somewhere in the vast universe is another inhabited planet with its own biology and ecosystems. In closing, Berkowitz reviews the methods that future scientists might use to identify planets that aren’t just habitable, but are actually inhabited.

Haqq-Misra is a research scientist with the Blue Marble Space Institute of Science, a nonprofit research institute with an interdisciplinary approach to studying the relationship between earth system science and the future of humanity. He is also a contributing editor for EARTH. Email: jacob@bmsis.org.

1. Acavate
2. Accordant junction
3. Alumotungstite
4. Arc spectrum
5. Assay ton
6. Bar plain
7. Bedding
8. Chadronian
9. Datum gravity
10. Encroachment
11. Eukrite
12. Exocyclic
13. Faciation
14. Feeding esker
15. Fransoletite
16. Free surface
17. Garbage
18. Harlequin opal
19. Histic epipedon
20. Holmquistite
21. Kehoeite
22. Ladder vein
23. Mesh
24. Metanauplius
25. Meta-uranospinite
26. Pellodite
27. Phenetics
28. Polygono-morph
29. Potassium alum
30. Referencing
31. River end
32. Sapanthracite
33. Seismic pulse
34. Soil manage-ment groups
35. Strandflat
36. Tabular dissepiment

This is a word search of terms from the Glossary of Geology. Check out GeoWord of the Day at www.americangeosciences.org/word. Words in the puzzle may be hidden horizontally, vertically or diagonally, and spelled in either forward or reverse order.

V	M	E	T	A	U	R	A	N	O	S	P	I	N	I	T	E	M	Y	C	P	Q	J	H	M
O	A	F	G	S	A	P	A	N	T	H	R	A	C	I	T	E	H	I	A	F	L	N	G	X
F	A	C	I	A	T	I	O	N	M	B	D	X	W	D	A	S	L	L	F	T	A	P	R	T
G	E	W	Q	Y	B	R	U	X	N	A	R	C	S	P	E	C	T	R	U	M	P	N	A	M
N	Y	N	I	E	V	R	E	D	D	A	L	P	O	L	Y	G	O	N	O	M	O	R	P	H
I	Y	U	C	S	T	R	A	N	D	F	L	A	T	C	O	C	N	P	H	T	N	F	O	C
C	E	U	K	R	I	T	E	G	P	M	E	R	O	E	H	I	Y	P	Y	X	I	R	T	F
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E	X	E	I	N	U	R	P	N	G	E	Z	E	C	A	A	E	K	N	J	E	A	E	M	R
R	S	C	T	Q	E	C	G	N	S	F	N	O	B	E	C	I	L	V	I	F	H	T	A	F
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H	A	F	O	U	P	B	X	D	D	I	J	O	W	U	N	S	U	V	N	M	N	T	C	V
Q	Z	H	T	L	C	F	V	B	D	O	U	F	E	T	L	D	J	V	U	M	E	P	F	U
R	E	T	A	B	U	L	A	R	D	I	S	S	E	P	I	M	E	N	T	K	B	S	J	T
K	D	I	W	A	C	C	O	R	D	A	N	T	J	U	N	C	T	I	O	N	C	H	H	X
X	N	U	I	S	O	I	L	M	A	N	A	G	E	M	E	N	T	G	R	O	U	P	S	H

Puzzle solution will appear in next month's issue of EARTH.

Solution to the January 2015 crossword

C	A	L	M	S		A	M	M	O		T	R	E	Y
A	S	E	A	N		D	O	O	R		R	I	S	E
L	E	A	S	E		A	U	R	A		A	S	P	S
F	A	L	S	E	P	R	E	G	N	A	N	C	Y	
			I	R	E			E	G	G	S			
G	A	F	F		T	E	R	N		A	F	O	O	T
R	N	A		L	I	R	A		F	R	A	N	C	E
I	N	E	V	I	T	A	B	I	L	I	T	I	E	S
P	A	R	O	L	E		B	L	O	C		C	A	T
S	T	Y	L	I		S	I	L	O		D	E	N	Y
			C	E	D	E			R	U	E			
	T	R	A	D	I	N	G	E	S	T	A	T	E	S
C	O	I	N		S	I	L	D		T	R	A	V	E
U	G	L	I		C	O	E	D		E	M	B	E	R
T	A	L	C		O	R	E	O		R	E	U	S	E

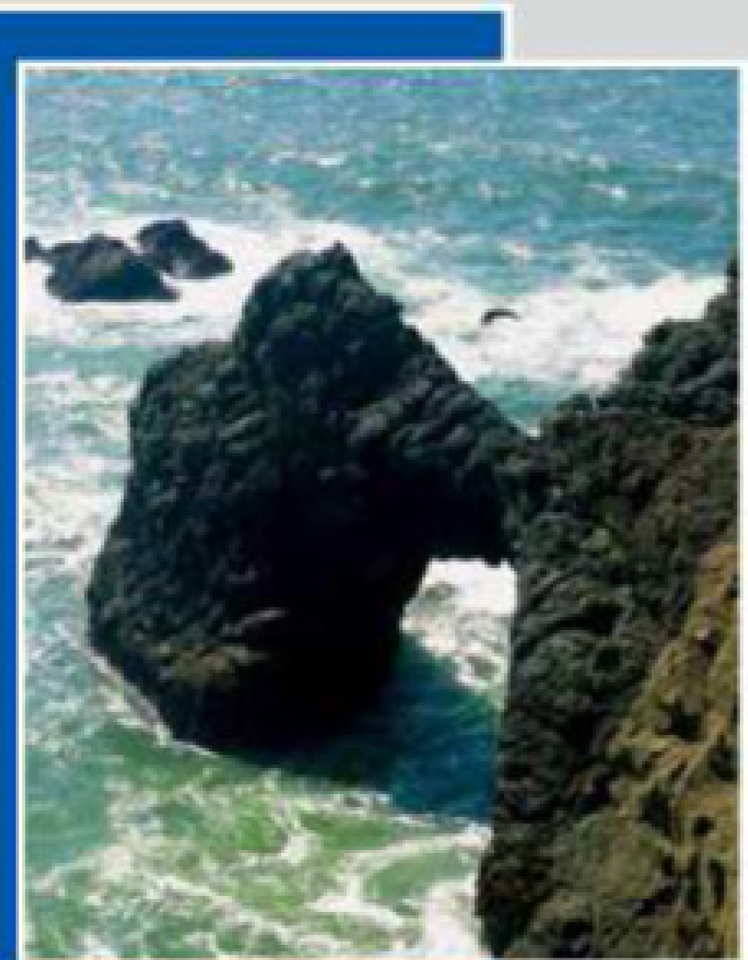
WHERE ON EARTH?

SUBMIT YOUR PHOTOS!
SEE DETAILS BELOW

CLUES

- These rock spires are fossil fumaroles. They formed when hot steam and gas rose through thick layers of preexisting volcanic deposits, welding otherwise weak pumice, ash and scoria into durable features that resisted erosion better than the surrounding rock. Their name alludes to their lofty, pointed peaks.
- The spires are located about 9 kilometers southeast of a lake known for its tremendous depth — with a maximum depth of 592 meters, it's one of the world's 10 deepest — as well as for the "magical" island that emerges from its brilliant blue waters.
- The layers from which the spires were carved were deposited prior to the massive volcanic eruption 7,700 years ago that led to the formation of the lake, which, despite its name, was not created by an extra-terrestrial impactor.

November Answer:



Pillow basalts make up the impressive rock arch at Point Bonita in California's Golden Gate National Recreation Area, the largest urban national park in the U.S. The geology of the surrounding area, which includes many other rock types, documents a 200-million-year record of crust formation, subduction, faulting, erosion and sea-level change. Photo is by Robin Rohrback.

November Winners:

John D. DeMartini (McKinleyville, Calif.)
Ellen Herron (Chapel Hill, N.C.)
John Karachewski (Walnut Creek, Calif.)
Glen S. Pearson (Red Bluff, Calif.)
Doris Sloan (Berkeley, Calif.)

HOW TO PLAY

NAME THE SPIRES AND WHERE THEY ARE LOCATED.

Where on Earth was this picture taken? Use these clues to guess and submit your answer via mail, email or Web by the last day of the month (February 28). Subscribers can also view contest photos and clues in EARTH's monthly digital editions. From those who answer correctly, EARTH staff will randomly draw the names of five people who will win 25 percent off any AGI publication, excluding the GeoRef Thesaurus and EARTH. Enter the contest at www.earthmagazine.org/whereonearth.

You can also submit entries to Where on Earth? EARTH, 4220 King Street, Alexandria, VA 22302 (postmarked dates on letters will be used).

EARTH also welcomes your photos to consider for the contest. Email your submissions to earth@earthmagazine.org. If we print your photo in EARTH, you'll receive a free one-year subscription or renewal and 25 percent off any AGI publication, excluding the Thesaurus and EARTH.

MINERAL RESOURCE OF THE MONTH

ANTIMONY

David Guberman, the antimony commodity specialist for the National Minerals Information Center at the U.S. Geological Survey, compiled the following information about antimony, widely used in alloys and in flame retardants.

Antimony is a lustrous silvery-white semimetal or metalloid. Archaeological and historical studies indicate that antimony and its mineral sulfides have been used by humans for at least six millennia. The alchemist Basil Valentine is sometimes credited with "discovering" the element; he described the extraction of metallic antimony from stibnite in his treatise "The Triumphal Chariot of Antimony," published sometime between 1350 and 1600. In the early 18th century, Jöns Jakob Berzelius chose the periodic symbol for antimony (Sb) based on stibium, which is the Latin name for stibnite.

Antimony is nonmalleable, hard and brittle and can be crushed to a powder. Compared with metals, antimony is a poor conductor of electricity and heat. Antimony is the 63rd-most abundant element in Earth's crust. It is less abundant than tin, arsenic and the rare earths, but more so than bismuth, mercury and silver. Antimony tends to concentrate in sulfide ores along with copper, lead and silver. It occurs sparingly as a free element, but when it does it is usually in association with arsenic, bismuth or silver.

The principal ore minerals of antimony are stibnite and jamesonite, but it can also be a byproduct of certain other minerals. Eighty percent of the world's antimony is produced from two types of deposits — carbonate replacement deposits and gold-antimony epithermal deposits.

The majority of antimony is consumed in the production of antimony trioxide (ATO), a compound used in flame-retardant materials. Combined with halogenated particles, ATO suppresses, reduces or delays the spread of flame. It is incorporated into adhesives, paints, plastics, rubber insulation, decorative foams, building materials and textiles, including upholstered furniture.

No marketable antimony has been mined in the United States since 2001, when the Sunshine Silver Mine in Idaho, which produced antimony as a byproduct, closed. The U.S. relies heavily on imports from China, which dominates global mine production of antimony ores and concentrates and which restricts the amount of antimony produced and exported annually.

As of 2014, several new sources of domestic antimony were in different stages of development. One company began mining stibnite ore for upgrade and sale at a restarted antimony mine in Nevada, and was in the process of acquiring a mill to process the ore and produce marketable antimony concentrate. There was also interest in exploring and mining the historic Yellow Pine Mine, a gold-antimony deposit in central Idaho, that produced antimony from the 1990s to 2001.

For more information on antimony and other mineral resources, visit: minerals.usgs.gov/minerals.

Stibnite is a principal ore of antimony.
Credit: PepperedJane

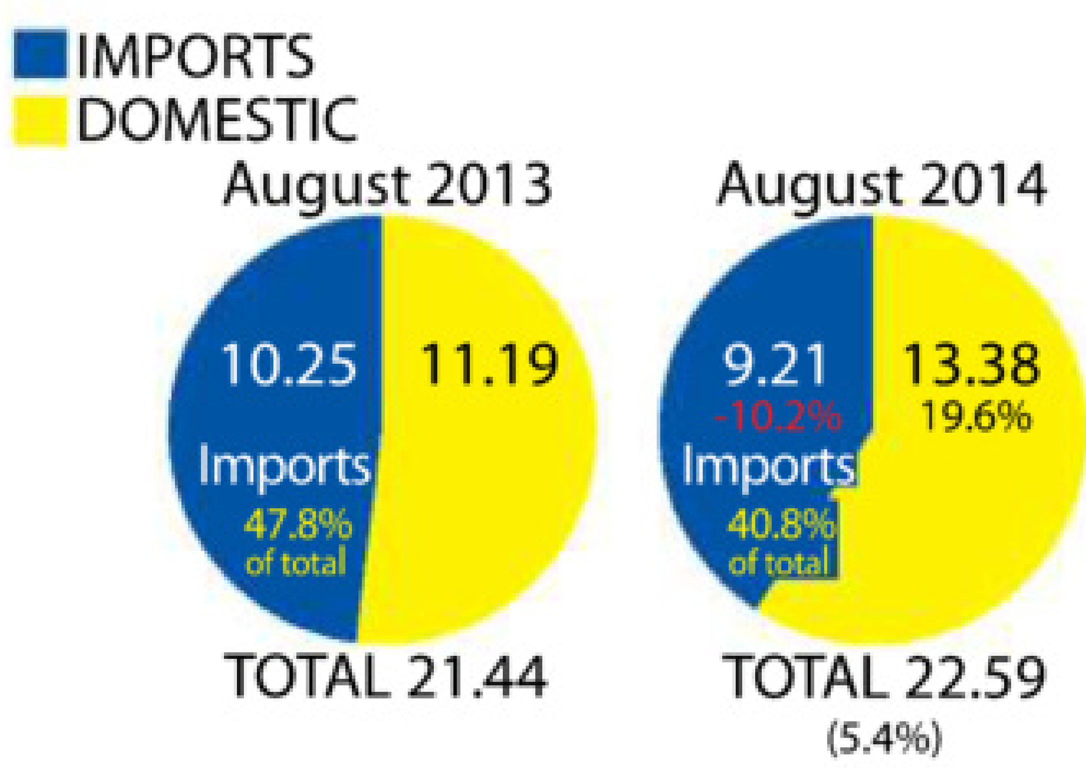
FUN FACTS

- The name antimony was derived from the Greek words, "anti," meaning not, and "monos," meaning alone, because antimony is normally found in complex ore bodies.
- In ancient times, powdered stibnite was, along with lead sulfide, a principal ingredient of kohl, the thick black paste used by the Egyptians and others as a cosmetic for coloring eyebrows and lining the eyes.
- In the Middle Ages, antimony was used as a "recyclable" laxative. It was swallowed in the form of a pea-sized pill and could be reused after passing through the digestive system.
- Antimony is added to fireworks to create glitter effects.

ANTIMONY PRODUCTION AND CONSUMPTION

- In 2013, China was the leading global producer, accounting for about 78 percent of world mine production, followed by Burma (6 percent), Russia (5 percent), Bolivia (3 percent) and Tajikistan (3 percent).
- China was also the leading consumer of antimony in 2013, followed by the United States and Japan.
- More than 50 percent of the antimony consumed globally is thought to be used in flame retardants.

ENERGY NOTES



U.S. Oil & Petroleum Imports (million of barrels per day)

Oil and petroleum imports data are preliminary numbers taken from the American Petroleum Institute's Monthly Statistical Report. For more information visit www.api.org.

With Glaciologist Lonnie Thompson

As a child growing up in Gassaway, W.Va., Lonnie Thompson was poor. When his father died while Thompson was a senior in high school, he realized he'd need to earn a reliable paycheck as quickly as possible. As an undergraduate at Marshall University in Huntington, W.Va., he knew he wanted to study science; he started off as a physics major before settling on geology. Later, when he arrived at Ohio State University (OSU) as a graduate student in 1971, Thompson's intent was to study coal geology, a practical choice that he believed would quickly secure him a job.

Lonnie Thompson at Qori Kalis Glacier in the Peruvian Andes in 2000.
Credit: Tom Nash, courtesy of Lonnie Thompson

During his first term, however, Thompson received a notice in his mailbox advertising a research position to examine ice cores at OSU's Institute of Polar Studies (now called the Byrd Polar and Climate Research Center). Thompson knew that glaciers cover just 10 percent of the planet, and that they're mostly located in places where people don't live, so he doubted he could ever make a living looking at ice. But he also knew that he could earn his degree more quickly if he held a research position, so he applied for the job.

That decision ultimately led to an illustrious career studying glacial ice. After several years deciphering the climate records preserved in the earliest cores retrieved from Greenland and Antarctica, he pioneered the study of glaciers in Earth's tropical and subtropical regions.

Thompson has received dozens of awards for his work, including the National Medal of Science and the Seligman Crystal, the International Glaciological Society's highest honor. In 2005, he was elected as a member of the National Academy of Sciences and a fellow of the American Association for the Advancement of Science, and in 2009, he was selected as a Foreign Member of the Chinese Academy of Sciences.

Thompson holds a joint appointment as an OSU distinguished university professor in the school of earth sciences and a senior research scientist in the Byrd Polar and Climate Research Center, which his wife, Ellen Mosley-Thompson, a distinguished university professor in OSU's department of geography, directs. Thompson recently spoke with EARTH contributor Terri Cook about the circumstances that launched his career, how a successful heart transplant in 2012 has influenced him, and why as a child he would bet his lunch money on the weather.

TC: How did you become interested in science?

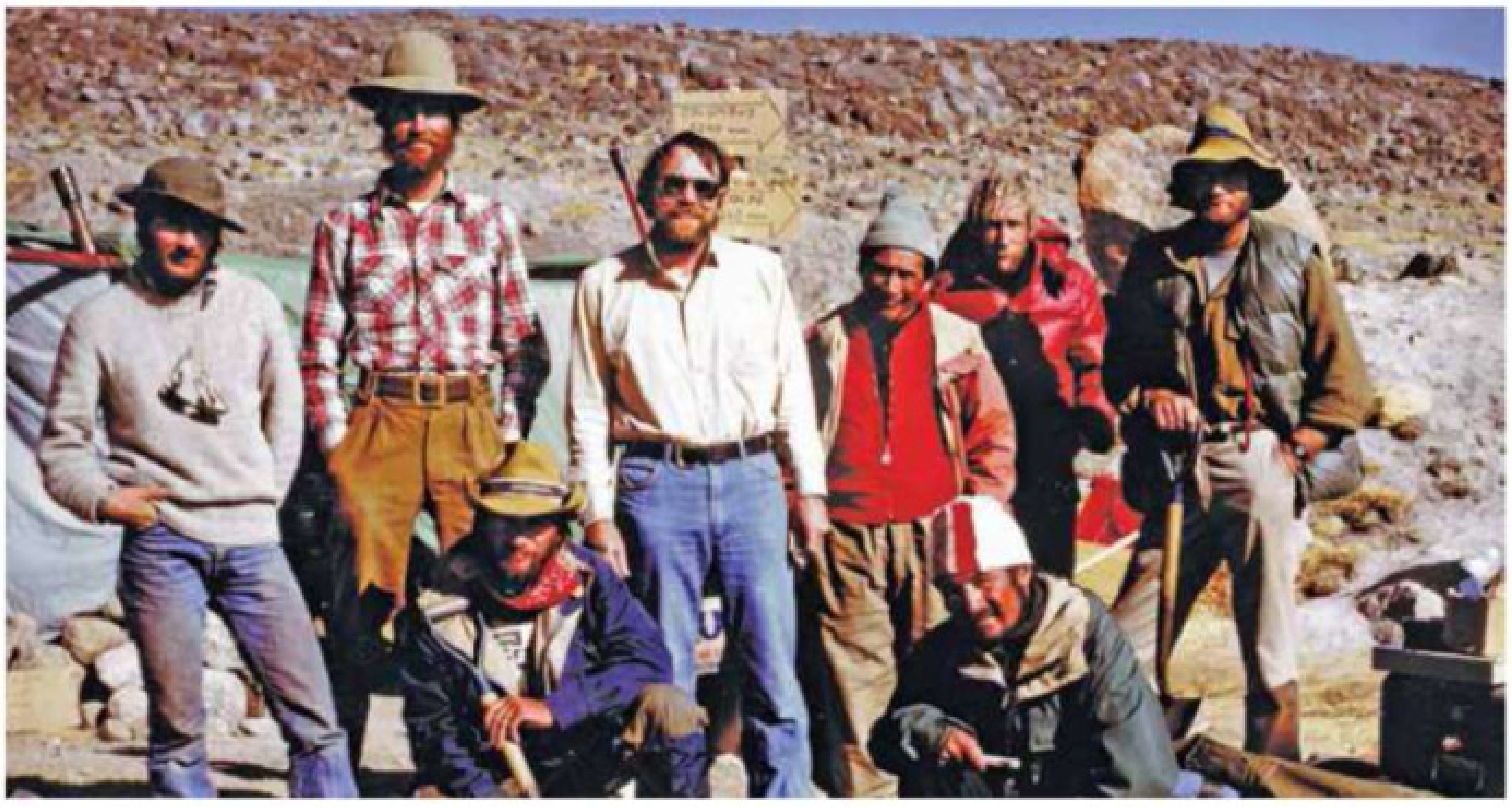
LT: In sixth grade, I became interested in the weather. I set up a weather station in the barn on our farm, and I became pretty good at predicting it. We were very poor, so at school I'd bet my lunch money on the forecast. Unfortunately, when you grow up in a poor community, there's a lot of negative feedback that discourages you from trying new things and keeps you from dreaming. It takes a lot of courage to overcome the negativity, and this was why it was so important to have motivated teachers and fellow students to inspire me and a mom who always stressed the importance of education.

TC: Why did you decide to take a risk and deviate from your plan of studying coal geology?

LT: I think circumstances in my early life played an important role. Two years after my dad passed away, my sister died in an automobile accident when she was only 19. Those events really brought home the fact that there are no guarantees in life, and that if you want to make a difference, you need to get on with it. To do that, you have to take risks. I've always felt that in life it's not really what happens to you, but how you choose to deal with adversity that's most important.

TC: What events focused your research on tropical ice?

LT: While working on my dissertation, I began thinking about trying to connect the research that was coming out of Antarctica with what was coming out of Greenland. It was a fascinating time because all the pioneers in our field were alive, including John Mercer, who had compiled two atlases of Earth's glaciers while working at the American Geographical Society. When Mercer came to OSU, he had boxes of aerial photos from around the world, and in those boxes, we found images of the Quelccaya ice cap in the Peruvian Andes. That set the stage. Once I visited the ice cap, I could see there was a climate record there. It then became a matter of how to extract that record.



Thompson led the team that first successfully cored a tropical glacier to bedrock at Quelccaya in Peru in 1983. It took three months to recover two cores.

Credit: Lonnie Thompson

TC: What role has luck played in your career?

LT: Drilling Quelccaya first was a lucky choice. We now know that it is the best site that we could have possibly chosen to look for a low-latitude record. We're still extracting new records from it 40 years later. Had Kilimanjaro been the first, we would never have figured [the record] out, because the surface of Kilimanjaro is not modern; it's ablated. There's serendipity in all these things, including the people you meet along the way. In general, a lot of success is built on the efforts of other people.

TC: Your initial expedition to Quelccaya failed in the first hour when the helicopters couldn't carry the gear up to 5,800 meters. How did you convince the National Science Foundation to keep funding you?

LT: That was my biggest failure; it shouldn't have happened. I had met with the helicopter crew the year before, and they said it'd be no problem to fly the ice drill in. But by the time the next year rolled around, there was a different crew. People have to be committed and willing to take risks to make things work. When that failed, we climbed up to the ice cap, sampled 25 meters down the wall of a crevasse, and extracted a 25-year record of El Niño events that we published in Science. We then began to develop a solar-powered drill that would break down into units that we could put on horses to make the two-day journey from the end of the road to the ice cap. But of course we needed funding, so we wrote another proposal. Fortunately, the Office of Climate Dynamics had a new program manager, Hassan Virji, who, despite some poor reviews, was willing to take a chance and fund us. If you got those kinds of reviews today, you wouldn't get funded, which is a problem. The idea that you have to know if something works before you even try it is really going to limit breakthroughs in science.

TC: Is there any advice that you would give to young researchers?

LT: I think you should listen to your elders because they've had experience, but at the end of the day, you've got to go with what you think is best and do your utmost to make sure you succeed. I'm a firm believer in the 10,000-hour rule: If you're going to be an expert in anything, you have to put in eight and a half to nine years of learning. When you're young, you can afford to make mistakes. That's the time to take risks; if you do and it works out, then you can change the whole direction of thinking. That's what science should be all about.

TC: Of all the awards you've received, which is the most meaningful to you?

LT: The first one, which was the Vega Medal from the Swedish Society [for Anthropology and Geography]. There was no money associated with it, but it was the people who had won the award previously — heroes like [Fridtjof] Nansen, [Robert] Scott, [Roald] Amundsen and [Richard] Byrd. These are the people I read about while growing up, and to think that I was awarded a medal that they had also received doesn't seem possible.

To recover two cores, in 2010, Thompson's team camped at an elevation of almost 4,900 meters atop this glacier near Puncak Jaya in Papua, Indonesia, one of just a few glaciers between the Himalayas and the Andes.

Credit: Lonnie Thompson

Thompson and his wife Ellen Mosley-Thompson, director of the Byrd Polar and Climate Research Center at Ohio State University, in the ice-core storage facility.
Credit: Lonnie Thompson

TC: What emotions have you experienced while working with glacial ice cores?

LT: Every time we drill at a new site, there is excitement when you finally hit bedrock, when you've accomplished a mission in a really remote part of the world that a lot of people would have said was impossible. My repeated trips to Quelccaya [which is melting] are also emotional; I've often thought of it as visiting a terminally ill patient. You know what's happening, and you know what the future will be. This ice is an extremely important part of our environment that I've had an opportunity to see and study [but] that future generations will not.

TC: When did it dawn on you that you were gathering not just a record of past climate, but also a record of human history?

LT: Quelccaya was the first place. The studies we wrote on the first core extracted with the solar-powered drill have been quoted in about 60 archaeological papers. To me the beauty of these ice studies is that we have an opportunity to work with scientists in other disciplines and learn from their perspectives. We bring to the table a calendar, and a temperature and precipitation history. In those early cultures in Peru, especially up on the Altiplano, both temperature and precipitation were critical to whether a civilization could exist there or not.

TC: What did your experience of receiving a heart transplant teach you?

LT: For a time it wasn't clear what the outcome would ultimately be. The situation was life threatening, but I learned a lot about myself and the people around me through it. For six months I survived on a turbine that was installed in my old heart. It was the bridge that allowed me to wait for a new heart that was a good match. I knew that I'd had 63 great years, and if the operation were successful, I'd have a few more. The worst thing I can think of is to live a life in which, when you're my age, you look back and wish you'd done something else. Life is not about living to be 100, but about making a difference while you're here.

TC: With this new heart, you've been given the gift of a second life. What do you hope to accomplish in it?

LT: I've thought a lot about that question. Certainly, there are a few additional [ice] records that I want to get, but I don't think that is my real purpose. I think that there's another opportunity, a more personal one, and I'm still sorting out just exactly what that is. I think, in all of us, there is a life force that connects us. I've noticed this in all the countries where I work. Once you get away from governments and deal with people, we're all the same, and somehow in that connection there should be a way to get us to work together to change the future of this planet. I'm really concerned about the track we're on; we haven't done anything to change our future. It wasn't my choice whether I wanted a heart transplant; it's the way things were. I believe it's the same with climate change issues — at the end of the day, we will deal with them because we'll have to. •

Thompson, winner of the 2005 National Medal of Science, was awarded the medal in a 2007 ceremony with President George W. Bush.
Credit: Ryan K. Morris, National Science and Technology Medals Foundation

February 17, 1977: Hydrothermal Vents Are Discovered

This image, taken on Feb. 17, 1977, records the discovery of deep-sea hydrothermal vents and dozens of previously unseen species of marine life.

Credit: WHOI Archives ©Woods Hole Oceanographic Institution

In early February 1977, as scientists aboard the research vessel (R/V) Knorr made their way across the Pacific waters off the northwest coast of South America, they had reason to suspect their expedition might find the success that had eluded others. Previous missions had identified their destination — a site on the ocean surface about 330 kilometers northeast of the Galápagos Islands, below which two tectonic plates rift apart — as a promising location from which to search for their intended target. Once there, the researchers would deploy a variety of tools, including manned and unmanned submersibles, to the ocean bottom in the hopes of directly spotting hydrothermal vents.

Such vents — where geothermally heated seawater spews from cracks in the seafloor back into the ocean — were theorized as a byproduct of plate tectonics. Given that plate tectonic theory itself had only gelled in the preceding couple of decades, geologists were eager to prove these vents existed. Earlier expeditions had documented warm-water anomalies, unusual rock and mineral deposits on the ocean floor, and other tantalizing evidence, all occurring near tectonically active areas as predicted. But no one had observed a vent up close.

Returning in 1977 to the Galápagos Rift, the scientists aboard the Knorr would not be disappointed. Less than a week after arriving on the scene, researchers searching the deep from inside the submersible vehicle "Alvin" came upon a plume of hot water issuing from the seafloor. This was the definitive proof they'd been after. But it wasn't the only cause for excitement. The scientists were greeted by another, wholly unexpected sight: life, and lots of it.

Hydrothermal Hints

Early clues that geothermally heated waters circulated through oceanic crust and vented into the overlying ocean emerged in the mid-1960s from explorations in the Red Sea. Despite its name, the Red Sea is actually a young and growing ocean, bisected — much like the Atlantic — by a mid-ocean ridge, or spreading center, where magma from the mantle wells up and cools to form fresh oceanic crust.

Several research cruises detected anomalously warm waters at depth above the Red Sea Rift. And sediment samples pulled from the seafloor were found to be enriched in metals like copper, iron and manganese, suggesting localized sources that were somehow supplying the metals.

These findings prompted explorations of other mid-ocean ridge systems in the Atlantic and Pacific and turned up additional evidence of hydrothermal systems. Ubiquitous seafloor basalts showed signs of having been infiltrated and metamorphosed by water at high temperatures: Veins of white quartz and brown sulfides pierced the rock, and alteration minerals like chlorite and epidote lent greenish hues to the predominantly black basalt.

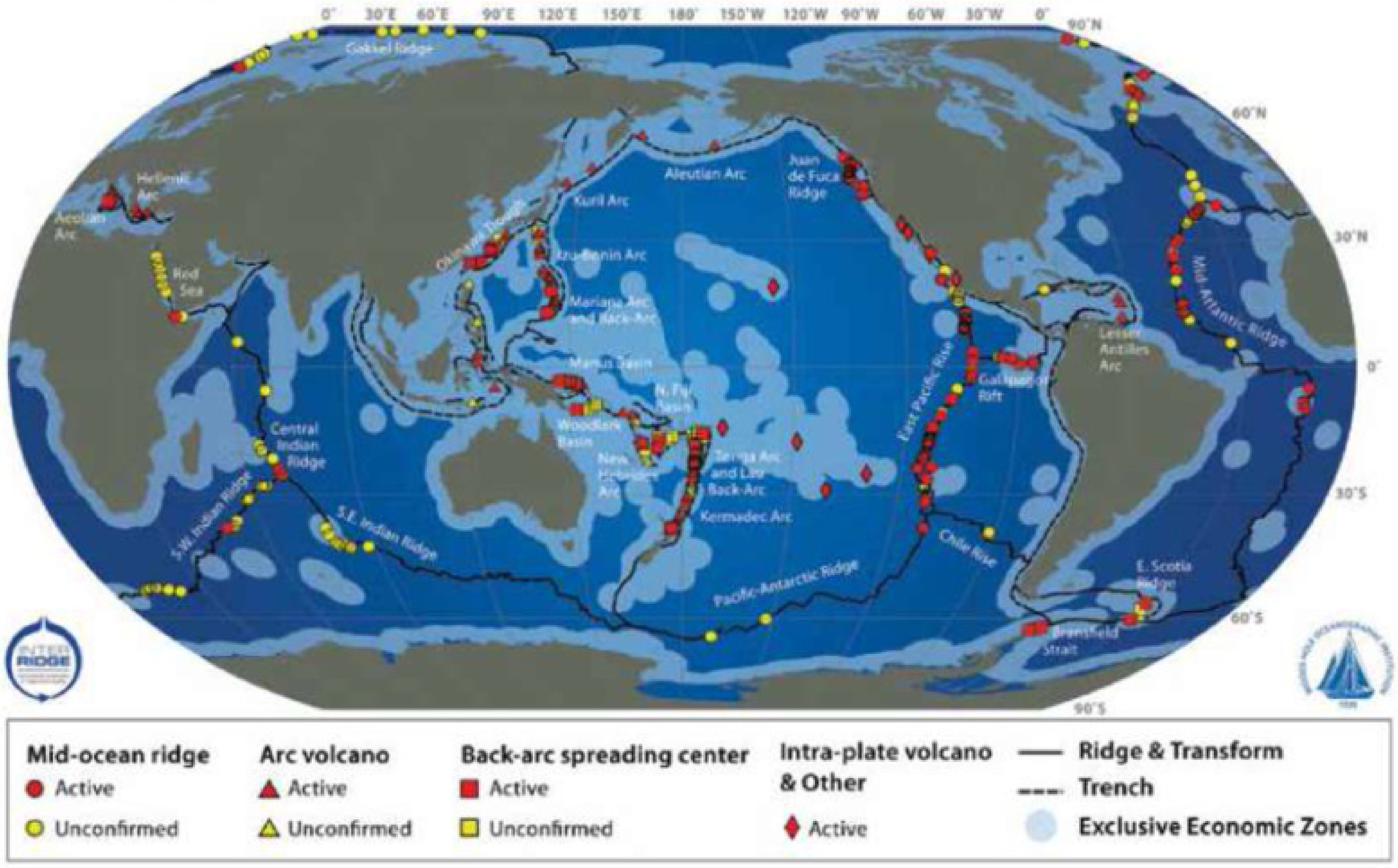
Measurements of heat flow through the ocean floor, taken by large probes sunk into the sediments, near active ridge systems also showed odd results. If heat were simply conducted through the crust from Earth's interior to the oceans, measured heat flows should be highest along the axis of the ridge (directly above the magmatic heat source) and then decrease steadily away from it. But the pattern of decreasing heat flow proved irregular. In particular, it was quite a bit lower than expected along the ridge, suggesting that something other than conduction was also ferrying heat away from the spreading center.

With remotely sensed evidence for hydrothermal vents mounting, it was time for scientists to dive down and take a closer look.

Scientists diving on the Galápagos Rift in the submersible Alvin in February 1977 discovered a type of ecosystem that subsists via chemosynthesis rather than photosynthesis; such an ecosystem was previously unknown on Earth.

Credit: WHOI Archives ©Woods Hole Oceanographic Institution

Global Distribution of Hydrothermal Vent Fields



Since their discovery in 1977, more than 500 active hydrothermal vent fields have been located around the world.

Credit: S. Beaulieu, K. Joyce, and S.A. Soule (WHOI), 2010

Galápagos Bound

One area that scientists focused their attention on after the early efforts in the Red Sea was the Galápagos Rift. This active east-west trending rift, more than 2,000 kilometers in length, separates the Cocos Plate to the north from the Nazca Plate to the south. (The Galápagos Islands themselves, and other nearby seamounts, are fed by volcanism from the Galápagos hot spot — a distinct feature, but one that affects the character of eruptions and seafloor topography along the spreading center near the hot spot.)

From 1966 to 1970, researchers from Scripps Institution of Oceanography made a series of visits to the rift, taking heat-flow measurements from aboard ships. They returned in 1972, equipped for the first time with a submersible vehicle called "Deep-Tow," which could be towed above the seafloor by a surface ship. Outfitted with cameras and other sensors, it offered the scientists their first actual view of the ocean bottom near the Galápagos Rift. Photographs taken by Deep-Tow showed large circular mounds, some covered in what appeared to be light-colored mineral crusts. Water temperature and heat-flow measurements again gave anomalous readings. And sonobuoys even detected scores of small earthquakes occurring in the area of the warm waters.

Each of the lines of evidence offered glimpses of where hydrothermal vents might be found. In 1976, Scripps scientists went back again, turning up yet more clues. A narrow slice of water — slightly warmer and with different chemistry than the surrounding seawater — extended nearly 40 meters above a large fracture in the ocean bottom, which was photographed by Deep-Tow. Nearby, more rocks appeared to be covered with white and yellow crusts. Images showing empty clamshells strewn on the seafloor (with a beer can purportedly among them) also intrigued the researchers.

Meanwhile, as exploration of the Galápagos Rift had progressed, another major research venture had been underway in the Atlantic. In the summer of 1974, and again in 1975, the ambitious French-American Mid-Ocean Undersea Study (FAMOUS) project brought together a small fleet of research vessels — including Alvin along with two French manned submersibles — to explore a section of the Mid-Atlantic Ridge southwest of the Azores.

For the first time, researchers dove to the heart of an underwater tectonic rift, observing the newly formed sheets and pillows of basalt that emerged. Despite hours of firsthand observation, tens of thousands of photos snapped and many measurements and rock samples collected, a direct view of vents in action again proved elusive. However, FAMOUS succeeded in proving the capability and utility of using manned submersibles to explore rift systems. And it wasn't long before a new expedition would bring Alvin to the Pacific to search through the multitude of hydrothermal hints at the Galápagos Rift.

Success at Last

On Feb. 12, 1977, the R/V Knorr, after venturing west from the Panama Canal, reached its destination northeast of the Galápagos Islands. On board were the expedition's leaders, Richard Von Herzen and Robert Ballard from Woods Hole Oceanographic Institution, along with a team of geoscientists and crew. With the help of detailed bathymetric maps and ocean-bottom transponders, the team determined its precise location over the rift before lowering the unmanned Acoustically Navigated Geological Underwater Survey (ANGUS) down for a scouting mission on Feb. 15.

Hovering just meters above the seafloor, ANGUS measured temperatures and snapped 3,000 photographs of the bottom — one every 10 seconds — as it was slowly towed along for 16 kilometers. Halfway into the 12-hour foray, ANGUS detected a jump in water temperature. It lasted less than three minutes before the temperature returned to normal — about

Artist's illustration of the towed camera sled ANGUS, which played a key role in the discovery of hydrothermal vents, vent organisms such as giant clams and tubeworms, and in 1979, the first "black smoker" vents.
Credit: Kathleen Cantner, AGI

2 degrees Celsius — but it was enough to excite scientists aboard the Knorr, who noted the time and location of the signal.

Once ANGUS was retrieved and its film removed and processed, the team began scanning through the photographs sequentially. In frame after frame, the scientists saw "an endless variety of sculptured pillow [lava] forms," Ballard recounted in an article he penned for Oceanus Magazine later in 1977. Slowly, they made their way to the shots corresponding with the temperature jump.

"The photograph taken just seconds before the temperature anomaly showed only barren, fresh-looking lava terrain," Ballard wrote. "But for thirteen frames (the length of the anomaly), the lava flow was covered with hundreds of white clams and brown mussel shells. This dense accumulation, never seen before in the deep sea, quickly appeared through a cloud of misty blue water and then disappeared from view."

Not wasting time, Alvin was prepped for its first dive into the Galápagos Rift. On Feb. 17, it descended 2.5 kilometers down to the ridge, carrying pilot Jack Donnelly along with scientists John Corliss from Oregon State University and Tjeerd van Andel from Stanford University. At the bottom, the trio patrolled toward the area of the temperature anomaly, peering through the submersible's windows at the desolate landscape below them.

When they reached their target, they "entered another world," Ballard recalled. "Coming out of small cracks cutting across the lava terrain was warm, shimmering water that quickly turned a cloudy blue as manganese and other chemicals in solution began to precipitate out." The team had spotted the proof of hydrothermal vents they'd been looking for. "But even more interesting," he noted, was the "dense biological community living in and around the vents."

Desert Oasis

Coming upon a colony of 30-centimeter-long white clams, Corliss is said to have called up to his graduate student at the surface: "Isn't the deep ocean supposed to be like a desert? ... Well, there's all these animals down here." Over the course of two dozen dives to the ridge that February and March, the team would document, in addition to clams and mussels, orange dandelion-like siphonophores, giant red tubeworms, blind white crabs and at least one purple octopus, among other animals. Not expecting to stumble upon such deep-dwelling life, the geoscientists (there were no biologists on the mission) did their best to collect specimens and preserve them. When the small supply of formaldehyde aboard ship was exhausted, the scientists used vodka as a preservative instead.

The team, in locating hydrothermal vents, paved the way for vastly expanded ideas about the bounds of life. Not only were there myriad new species waiting to be discovered, but at the time, all food chains were thought to be dependent, at their base, on photosynthesis and the sun. The deep-ocean life that was known relied on the remains of dead photosynthetic plankton and larger animals that sank through the water column.

The basis of the vent food chains, it was later unraveled, was chemosynthesis. Predators subsisted on microbes and other organisms that made meals out of chemicals like hydrogen sulfide in the hot fluids pouring from the vents, as well the subsequent minerals that precipitated out of the fluids when they came in contact with cold seawater — all without the aid of sunlight.

The findings of the 1977 mission also allowed scientists to better address major unresolved questions in earth science. Heat transport from Earth's interior as well as ocean chemistry, for instance, could be better explained with the understanding that cold seawater circulated through warm, fresh crust near spreading centers. In the process, the water — superheated to temperatures approaching 400 degrees Celsius — deposited some minerals while leaching others. Vent systems also began to make sense as the origin of massive, ophiolite-associated metal ore deposits on land.

Numerous subsequent explorations and research cruises have since carried on studying the unique geology, chemistry and life of hydrothermal vent systems. A return mission to the Galápagos Rift in spring 1979 brought to the site the first biologists, who began thoroughly cataloging the array of animals thriving there. Later that year, researchers in Alvin spotted the first "black smoker," a vent belching a dark plume of sulfide-laden water, on a section of the East Pacific Rise near the Gulf of California.

To date, more than 500 active hydrothermal vent fields have been located. And with so much seafloor left to search, and academic — and now commercial — explorations ongoing, there may be many more discovered.

Timothy Oleson

Please visit our website, www.earthmagazine.org/classifieds, for these and many other current career opportunities.

CAREER OPPORTUNITIES

ASSOCIATE PROFESSOR – GEOTHERMAL SPECIALIST (TENURE-TRACK)

The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno seeks applicants with expertise in geothermal energy research. Nevada is one of the most exciting regions in the world to do research in the geosciences and one of the best in the U.S. for the study of geothermal resources.

Position Responsibilities: The primary responsibilities of this position will be to develop broad programs in research and education in the field of geothermal energy while serving as Director of the Great Basin Center for Geothermal Energy. The applicant is expected to conduct a nationally competitive research program that will include innovative approaches to understanding the complexities of fluid flow in the crust with a concentration on Nevada and the surrounding Great Basin region. The successful candidate will also be expected to contribute to the development of datasets and reports on Nevada's geothermal resources, maintain geothermal databases as part of NGDS (National Geothermal Data System), and provide state resource assessments. Education will include teaching courses in geothermal related topics in the Department of Geological Sciences and Engineering (DGSE), supervising graduate students, and contributing to developing a geothermal curriculum. Research and educational efforts will involve multi-departmental and multi-institutional efforts, with scientists from academia, industry, other institutions, and government labs. The successful candidate will be asked to communicate effectively with the public and community leaders regarding the geothermal resources of Nevada.

Qualifications: Applicants must have a doctorate in geology, geologic engineering, geophysics, or a related geoscience field by the time of hire and a demonstrated record of research on topics related to geothermal energy as indicated by dissertation research, industry experience, and/or peer-reviewed publications. The successful candidate must have at least 5 years of postdoctoral experience (either in industry or academia) in geothermal research in such areas as rock mechanics, 3D modeling, geophysical techniques, reservoir engineering, and/or geochemistry. Excellent communication skills, as demonstrated in written application materials; commitment to public service; potential for, or established record of publications; and ability to attract funding are essential. The successful candidate must also have demonstrated ability to develop/coordinate programs and work in teams to accomplish major goals.

Because the individuals will be competing for funding from a variety of sources, including industry and federal agencies, for fundamental and applied geoscience research (e.g., NSF, DOE, and USGS), preference will be given to candidates who explain achievable plans for funded research on Nevada-focused topics in geothermal energy in their letters of interest. In addition, preference will be given to candidates who understand NBMG's role as the state geological survey of Nevada, especially to those who can articulate a plan of how NBMG can better serve stakeholders (citizens, government, and industry) on issues related to geothermal resources.

Salary and Date of Appointment: The position will be a tenure-track faculty appointment at the associate professor level with an academic-year base salary that is competitive with other research universities. Starting date will be July 1, 2015 or shortly thereafter, depending on availability of the successful candidate.

Application: Please submit a letter expressing your interest in the position, research plans; names, e-mail, postal addresses, and telephone numbers of

at least three references; a complete vita; and electronic copies of up to three of your publications to https://www.unrsearch.com/postings/16685. Application deadline is March 1, 2015. For further information about NBMG, please consult our website (http://www.nbmg.unr.edu).

The University of Nevada, Reno is committed to Equal Employment Opportunity/Affirmative Action in recruitment of its students and employees and does not discriminate on the basis of race, color, religion, sex, age, creed, national origin, veteran status, physical or mental disability, and sexual orientation. The University of Nevada employs only United States citizens and aliens lawfully authorized to work in the United States. Women and under-represented groups are encouraged to apply.

SURVEY DIRECTOR AND STATE GEOLOGIST WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY UNIVERSITY OF WISCONSIN-EXTENSION

Madison, Wisconsin, is home to the State Capitol, the flagship campus of the University of Wisconsin System, and the Wisconsin Geological Survey. Surrounded by lakes, our bike-friendly college town is a vibrant hub of art, music, local foods, and outdoor activities. Our city consistently ranks as a top place to live, work, and play.

The University of Wisconsin–Extension (an EEO/AA employer) is seeking a PhD-level geoscientist to serve as Survey Director and State Geologist. The Survey employs 26 professionals and has an average annual budget of $2 million dollars. Our academic atmosphere, focus on research and outreach, and compact size set the WGNHS apart from most geological research organizations. A complete position description is available at: http://WisconsinGeologicalSurvey.org/jobs. Application deadline: February 28, 2015.

RESEARCH GEOLOGIST/ STRATIGRAPHER INDIANA GEOLOGICAL SURVEY

The Indiana Geological Survey, a research institute of Indiana University, seeks applications for a research geologist / stratigrapher to perform geologic mapping and basic and applied research related to the bedrock stratigraphy of the State of Indiana. Significant duties include participation in the USGS-sponsored STATEMAP projects. Masters degree (Ph.D preferred), publications record, and 3 years' experience required. Salary range $50-60 K with ample University benefits package. Complete job posting is on the IGS Website (igs.indiana.edu). Application deadline is March 5, 2015, with an anticipated starting date of July 1, 2015.

ASSISTANT PROFESSOR NEOTECTONICS (TENURE-TRACK)

The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno seeks applicants with expertise in neotectonics and Quaternary geology. Nevada is one of the most exciting regions in the world to conduct research in the geosciences, particularly in the fields of neotectonics and geologic hazards.

Position Responsibilities: The primary responsibilities of this position will be to develop programs in research and education in the field of neotectonics with emphasis on paleoseismic and earthquake hazard research in Nevada and the surrounding region. Research will focus on landscape evolution primarily as it relates to Quaternary faulting, utilizing innovative approaches, such as LiDAR, to conduct detailed geologic mapping and dating of Quaternary units and surfaces. The successful candidate will also be expected to contribute to the development of datasets and reports on Nevada's Quaternary faults and seismic activity, including

periodic assessments and syntheses of hazards facing its major cities and infrastructure. Education will include teaching courses in the successful candidate's area of expertise, such as neotectonics, geologic hazards, and Quaternary geology in the Department of Geological Sciences and Engineering and supervising graduate students. Research and educational efforts will involve integrated multi-departmental (e.g. Nevada Seismological Laboratory) and multi-institutional efforts, with scientists from academia, industry, other institutions, and government labs. The successful candidate will be asked to communicate effectively with the public and community leaders regarding natural hazards in Nevada and coordinate mitigation and response efforts with local and federal emergency management agencies.

Qualifications: Applicants must have a doctorate in geology or a related geoscience field by the time of hire and a demonstrated record of research on topics related to neotectonics as indicated by dissertation research, industry experience, and/or peer-reviewed publications. Excellent communication skills, as demonstrated in written application materials; commitment to public service; potential for, or established record of publications; and ability to attract funding are essential. The successful candidate must also have the ability to develop and coordinate programs and work in teams to accomplish major goals.

Preference will be given to candidates with academic or industry experience in neotectonics. Expertise in paleoseismology (e.g. trenching), surficial processes, Quaternary dating techniques, LiDAR, and/or InSAR will be valued. Preference will be given to candidates who have demonstrated research productivity with publications in peer-reviewed literature. The successful candidate will compete for funding from a variety of sources, including federal agencies interested in fundamental and applied geoscience research (e.g., NSF, USGS, Department of Energy, and Bureau of Land Management) and industry. Therefore, preference will be given to candidates who explain achievable plans for funded research on Nevada-focused topics in neotectonics in their letters of interest. In addition, preference will be given to candidates who understand the role of NBMG as the state geological survey of Nevada and can articulate how NBMG can better serve stakeholders (citizens, government, and industry) on issues related to geologic hazards.

Salary and Date of Appointment: The position will be a tenure-track faculty appointment at the assistant professor level with an academic-year base salary that is competitive with other research universities. Starting date will be July 1, 2015 or shortly thereafter, depending on availability of the successful candidate.

To apply, please visit: https://www.unrsearch.com/postings/16813. Please submit a letter expressing your interest in the position and research plans; names, e-mail addresses, postal addresses, and telephone numbers of at least three references; a complete curriculum vitae; and electronic copies of up to three of your publications to http://jobs.unr.edu/. Application deadline is March 10, 2015. For further information about NBMG, please consult our website (http://www.nbmg.unr.edu).

The University of Nevada, Reno is committed to Equal Employment Opportunity/Affirmative Action in recruitment of its students and employees and does not discriminate on the basis of race, color, religion, sex, age, creed, national origin, veteran status, physical or mental disability, and sexual orientation. The University of Nevada employs only United States citizens and aliens lawfully authorized to work in the United States. Women and under-represented groups are encouraged to apply.

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AGIF american geosciences institute foundation

The AGI Foundation's programs impact young people, educators, researchers, the public and policymakers, all who comprise the geoscientists and informed citizens of tomorrow. AGI Foundation's most recognized programs focus on geoscience STEM educational excellence and workforce development, and public awareness and government affairs. Widely acclaimed examples include the most prestigious endowed Fisher Congressional Fellowship, development of inquiry-based geoscience curricula for elementary and secondary school, conducting teacher academies to improve instruction of the geosciences, collection and analysis of geoscience workforce status and trends, and award winning publications and training materials to increase awareness and geoscience literacy by students, the public and professionals.

A major new initiative that the AGI Foundation is working to fund is the implementation of the new AGI Center for Geoscience Education and Public Understanding. The Center builds upon the foundation of the AGI and capitalizes on its strength as a federation of 49 scientific and professional geoscience societies representing a quarter of a million practicing geoscientists in the United States.

Critical new initiatives of the center require new funding from the AGI Foundation, include the following focus areas:

- Understanding the Status of U.S. Earth Science Education with the 2013 "roll-out" of the Nation's new science standards in which 26 States have signed on and 40 states are expected to fully adopt;
- Supporting innovative Energy Education;
- Conducting and distributing outcomes from Geoscience Critical Issue Forums;
- Expanding the scope and distribution of geoscience career materials and workforce information;
- More outreach to students positioned earlier in the "geoscience education flow".

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February 2:
A Day Long Celebrated for Its Seasonal Ties

John Copeland

February is an odd month. It is the only month not named for a god, a number or a Roman Emperor. It is named for a Roman festival, which seems appropriate this year given that February kicks off with the Super Bowl on Feb. 1. The festival, Februa, was a revel of purification. (Super Bowl Sunday is kind of the opposite!)

Februa predates ancient Rome; the festival arose to honor the Etruscan deity, Februus, the god of purification and the underworld. It was a time of atonement for the Etruscans and Romans. It may seem premature to have any regrets when the year has just begun, but before Julius Caesar reformed Rome's calendar, February was the last month of the year.

While the Romans were "festively purifying" themselves, other groups were celebrating a fire goddess, sheep, furry animals (though not groundhogs), and much later, church candles. All of these celebrations occurred on Feb. 2. At first glance, these rites may seem unrelated, but on the contrary, they are indeed.

Around the world, our ancestors celebrated specific days of the year as part of the cycle of the seasons. Feb. 2 is one of those days, falling exactly halfway between the winter solstice and the spring equinox. By this date, daylight has increased markedly since the winter solstice some six weeks earlier. In ancient times, this halfway point was called a Cross Quarter Day.

Nearly every ancient culture divided the year into four parts marked by the Winter Solstice, the Vernal Equinox, the Summer Solstice and the Autumnal Equinox. Today, we still recognize these as demarcating our seasons. Our ancestors further divided the year at the halfway points between the solstices and the equinoxes. These divisions are the Cross Quarter Days: Feb. 2, May 1, Aug. 1 and Oct. 31.

Feb. 2 is the first Cross Quarter Day of the year. The ancient Celts celebrated the first stirrings of spring and the onset of lactation in ewes, soon to start lambing, with the Imbolc festival. The 2nd is also Brigid's Day. Originally revered as a Celtic fire goddess, Brigid was so popular that she was embraced by the early Catholic Church and canonized as a saint. Both Brigid the fire goddess and St. Brigid were associated with sacred fire, holy wells and springs. And both heralded the transition from the dark season of winter into springtime.

In the early Christian tradition, Feb. 2 was celebrated as Candlemas, when all of the candles that would be used in churches during the coming year were blessed — it was a mass for the candles. In medieval times, when the festival became more widespread, Candlemas became a festival of lights. During the dark and gloomy February, the shadowy recesses of medieval churches twinkled brightly as a procession of the congregation carried lit candles around the church and the candles were blessed by the priest. The parishioners took these candles home, where they were thought to be talismans to ward off storms, demons and other evils. The custom lasted in England until the Reformation when it was banned as promoting veneration of magical objects. Even so, the symbol of lighted candles was too ingrained in popular culture to be entirely cast aside. In many areas of Great Britain, traces of the festival lingered until recently.

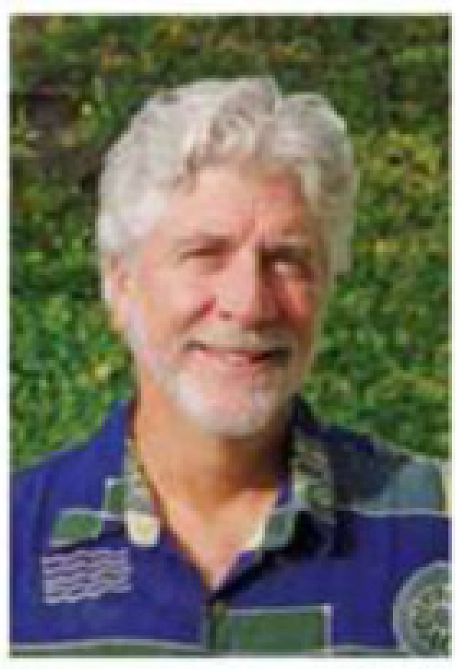
Today, of course, we celebrate Feb. 2 as Groundhog Day, although originally the celebration wasn't about groundhogs. In France and England, folk traditions maintained that Feb. 2 was when bears emerged from hibernation to inspect the weather. In Germany, meanwhile, it was the badgers that emerged to check the weather. But if the bears or the badgers chose to return to their dens, it portended at least another 40 days of severe weather.

In colonial times, German immigrants settled in Pennsylvania, bringing their traditions with them, including the hibernation day celebration. However, instead of badgers, they found lots of groundhogs, or woodchucks. The German settlers quickly embraced the "groundhog" to fit their lore.

The earliest-known American reference to Groundhog Day can be found in the Historical Society of Berks County in Reading, Pa. In 1841, James Morris, a storekeeper in nearby Morgantown, Pa., recorded in his diary:

"Last Tuesday, the 2nd, was Candlemas day, the day on which, according to the Germans, the Groundhog peeps out of his winter quarters and if he sees his shadow he pops back for another six weeks nap, but if the day be cloudy he remains out, as the weather is to be moderate."

Today, Groundhog Day has grown into a full-blown festival, with Punxsutawney Phil presiding. But even if Phil sees his shadow, you can rest assured the days are getting longer and winter is coming to an end.



Credit: Fran LoCascio

Copeland is a filmmaker in California who has produced television programs ranging from "Babylon 5" to "Faces of Earth" (produced with the American Geosciences Institute). Copeland also works with MIT's Experimental Study Group to instruct undergraduate science and engineering students in the art of visual communication and storytelling. The views expressed are his own.